72-31,719

KEPFERLE, Roy C., 1926-
STRATIGRAPHY, PETROLOGY, AND DEPOSITIONAL ENVIRONMENT OF THE KENWOOD SILTSTONE MEMBER, BORDEN FORMATION (MISSISSIPPIAN), KENTUCKY AND INDIANA.

University of Cincinnati, Ph.D., 1972
Geology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

STRATIGRAPHY, PETROLOGY, AND DEPOSITIONAL ENVIRONMENT OF THE KENWOOD SILTSTONE MEMBER, BORDEN FORMATION (MISSISSIPPIAN), KENTUCKY AND INDIANA

A dissertation submitted to the

Division of Graduate Studies
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

1972

BY

Roy C. Kepferle

A.B., University of Colorado, 1950
M.S., South Dakota School of Mines and Technology, 1954

UNIVERSITY OF CINCINNATI

May 15 *19* 72

I hereby recommend that the thesis prepared under my supervision by Roy C. Kepferle

entitled Stratigraphy, Petrology, and Depositional Environment of the Kenwood Siltstone Member, Borden Formation (Mississippian), Kentucky and Indiana

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

Wayne A. Pryor, Chairman

Paul Edwin Potter

Kenneth E. Caster

Form 668—Grad. School—1M—3-69

PLEASE NOTE:

Some pages may have

indistinct print.

Filmed as received.

University Microfilms, A Xerox Education Company

Contents

Contents--Continued

Contents--Continued

ILLUSTRATIONS

Plates

[Plates 1-12 follow Appendix A]

Figures

TABLES

STRATIGRAPHY, PETROLOGY, AND DEPOSITIONAL ENVIRONMENT OF THE KENWOOD SILTSTONE MEMBER, BORDEN FORMATION (MISSISSIPPIAN), KENTUCKY AND INDIANA

by Roy C. Kepferle

ABSTRACT

The Kenwood Siltstone Member of the Borden Formation (Mississippian) constitutes a wedge of sediment that thins from 85 feet to zero across a width of 10 miles and that extends for 50 miles along depositional strike from southern Indiana southeastward into north-central Kentucky. Paleocurrent studies of the Kenwood and analysis of a vertical profile through the Borden indicate the siltstone beds were deposited as a turbidite sequence that debouched fan-wise from two dispersal centers along the front of a prograding platform of sediments. The front of this platform defines the distal extent of the Catskill-Pocono delta system that began building westward in Late Devonian time. The cessation of the westward progradation is recorded by a widespread, burrowed, glauconite-strewn surface on the sediment platform. The glauconite is believed to have originated during a depositional lacuna in Kentucky and Indiana following the final stages of the Acadian orogeny in the east.

Detailed petrologic analysis of the Kenwood indicates two facies are present, an illitic clay to silt shale and an illitic arkosic siltstone. The siltstone is poorly sorted, immature, and medium-grained, and is strongly fine-skewed and leptokurtic.

Textural data plotted on a C-M diagram fall near the fine end of the turbidite field and in the field for pelagic suspension.

Internal bedding sequences are characterized by planar bedding laminae, but locally include the complete Bouma-sequence. Sole marks consist mainly of grooves, occasional flutes and trace fossils. Paleocurrents were generally west-southwest in water depth postulated as circalittoral (150 to 600 feet). Such a paleocurrent pattern in the Early Mississippian rocks of Kentucky appears to preclude an emergent area in the vicinity of the Cincinnati arch.

The Kenwood Siltstone Member is typcial of similar siltstone units in the terrigenous clastics of the Borden Formation. The siltstone beds are generally fewer than 40 in a given sequence and all appear to have had an eastern origin. These units include the Farmers Siltstone Member and the "Rockcastle freestone" beds of the Wildie Member in Kentucky and the Edwardsville and Lampkins sandstones in Indiana. The tectonic setting and magnitude of all of these units preclude designating them as flysch in spite of their turbidite origin. They appear to have originated as thin, circalittoral fans at the base of a prograding deltaic platform.

INTRODUCTION

The paleogeography for a given geologic time, properly interpreted, enables more accurate predictions of the location and distribution of economically important sedimentary facies. The sedimentary rocks exposed in north-central Kentucky and southern Indiana contain important keys to the interpretation of the paleogeography of that area for Early Mississippian time. Located now on the gentle west flank of the Cincinnati arch, these rocks are the link between two distinct depositional environments: the dominantly fluviatile geosynclinal sediments of the Appalachian basin to the east and the marine sediments of the Illinois basin and the Ouachita trough to the west (fig. 1).

A major difficulty in recognizing the interpretive keys in the Borden is the complexity of the interstratification of its sediments, which are predominantly siltstone and shale. Because of this complexity, a comprehensive petrographic and stratigraphic study of the entire Borden would be formidable. A more realistic approach is to study in detail one of the more distinctive subdivisions of the Borden and to relate the results to the Borden as a whole.

The Kenwood Siltstone Member in the lower Borden was chosen for this detailed study. Besides being lithologically distinct, the Kenwood is moderately well exposed and restricted areally. An added important distinction not shared by other members of the

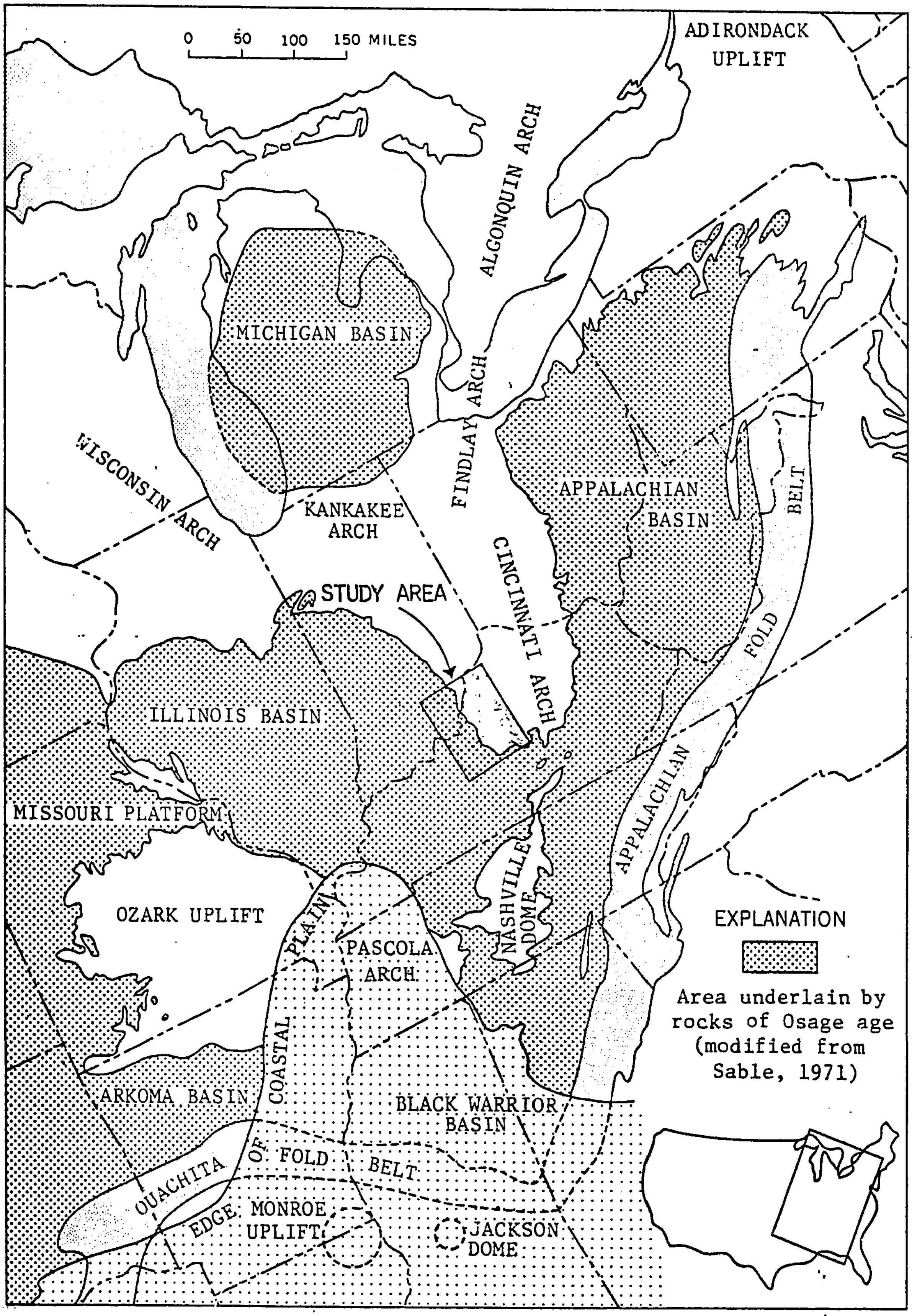


Figure 1. Map showing relation of tectonic elements in the eastern United States, the area underlain by the Borden Formation and equivalent rocks, and the study area.

Borden Formation in this area, is that the Kenwood appears to be a turbidite sequence that contains clear evidence of paleocurrent direction. The possibility that the Kenwood is a turbidite sequence, furthermore, enhances its value as a stratigraphic marker: a single turbidite bed is a natural time stratigraphic unit, and time-stratigraphic units are among the more important keys in any paleogeographic reconstruction.

The paleocurrent data, stratigraphy, bedding characteristics and trace fossil content are used in constructing a depositional model for the Kenwood. Paleocurrent data combined with compositional studies point to a possible source of the Kenwood. A facies analysis of a vertical profile through the entire Borden Formation is used to extrapolate successive depositional environments of the Borden in the study area. Finally, a correlation of the study area with the Appalachian basin is summarized in a regional paleogeography.

Acknowledgements

The direction and guidance by my major advisor, Prof. Wayne A. Pryor of the University of Cincinnati, is gratefully acknowledged. Laboratory assistance in the form of thin-section and textural analysis was furnished in part by the Sedimentation Laboratory, U. S. Geological Survey, Denver, Colorado. Mr. Robert W. Banks drafted the illustrations. Support for part of the field work and travel expenses was furnished by a Penrose Grant from the Geological Society of America. I deeply appreciate the access to

Bernheim Forest courteously extended by Mr. James Lawrence, Chief Ranger, Mr. Frank Bunce, Superintendant, and others of the staff at the forest. Drs. Henry H. Gray and Leroy E. Becker of the Indiana Geological Survey courteously furnished access to stratigraphic information in their files. I am indebted to many of my colleagues in the Branch of Central Environmental Geology in the Kentucky mapping project of the U. S. Geological Survey and the Kentucky Geological Survey, particularly to Mr. Warren L. Peterson, who deserves equal credit for recognition of the Borden delta front in the outcrop area of central Kentucky and whose stimulating discussions greatly assisted in the development of my concepts of the depositional environment of the Kenwood Siltstone Member. I thank especially Prof. Paul Edwin Potter, University of Cincinnati, whose early encouragement and interest furnished me the impetus to undertake the study and who critically read the manuscript. I also benefitted from visits to the outcrop area by Prof. Francis J. Pettijohn and students from the John Hopkins University, and Dr. Alan F. Thomson of the Shell Development Company. The manuscript benefitted from additional reviews by Prof. Kenneth E. Caster and Judith A. Bechtel of the University of Cincinnati, and by Mr. Wallace de Witt, Jr., of the U. S. Geological Survey. Ultimate responsibility for the context of this report is, of course, my own. Finally, I thank my wife, Rhua, and our children whose patient understanding enabled me to complete the study.

Location and Physiography

The Borden Formation crops out around the flanks of the Cincinnati arch. The study area encompasses that part of the Borden containing the Kenwood Siltstone Member, and extends for 50 miles south-southeastward in a zone about 10 miles wide from just north of New Albany, in Floyd County, Ind., to about 10 miles south of Bardstown, in Nelson County, Ky., and includes parts of Jefferson, Bullitt, Hardin and Larue Counties, Ky. (figs. 2 and 7).

In this area the most prominent physiographic feature is a steep south-trending escarpment capped by the resistant upper part of the Borden Formation. This escarpment, breached by the Ohio River, is called the Knobstone Escarpment in Indiana and the Muldraugh Escarpment in Kentucky. It rises from 200 to 300 feet above the siltstone ledges of the Kenwood. The Kenwood appears along the base of this escarpment and caps many low hills to the east in the physiographic subdivision called The Knobs.

Review of previous work

Early studies in the Lower Mississippian rocks of the region were chiefly stratigraphic or paleontologic. Excellent summaries of much of this early work are presented by Butts (1922) and Stockdale (1931, 1939). Weller (1898, p. 308) was one of the first to present a paleogeographic reconstruction of the area. He envisioned a quiet interior sea opening to the northwest, with Cincinnati island on the east. Until recently, the only detailed geologic mapping in the study area was the coverage of Jefferson

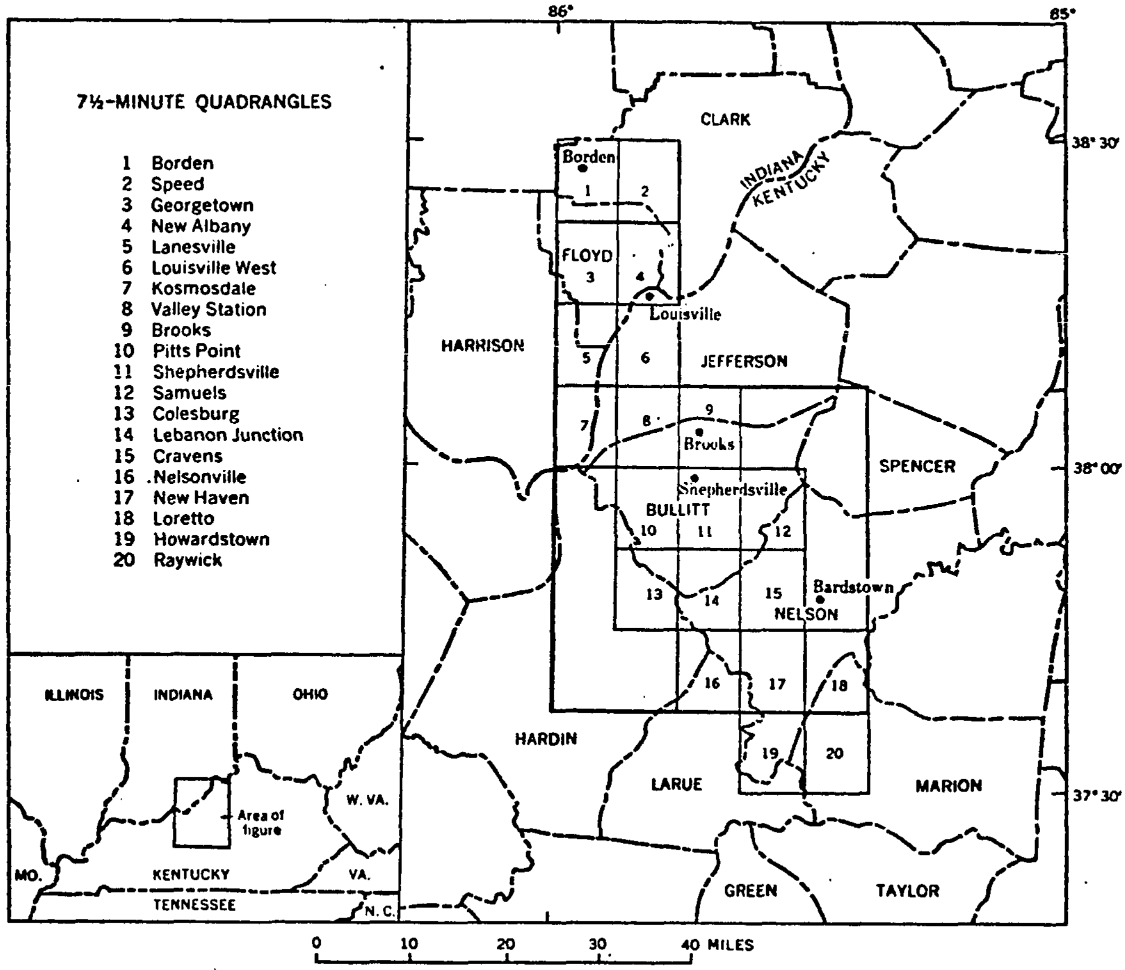


Figure 2. Index map of north-central Kentucky and adjacent areas showing counties and quadrangles referred to in text (heavy line outlines areas of figs. 7-12).

County, Kentucky (Butts, 1915). Some of the early petrographic studies were completed as a byproduct of this mapping, but most have been related to economic uses of the clays and sands, and the resulting data consist chiefly of chemical and size analyses (Stockdale, 1939, p. 61-62). For twenty years following Stockdale's work, studies of the Borden were chiefly paleontologic (Gutschick, 1954; Conkin, 1954, 1956, 1957, 1960).

Recent geologic quadrangle mapping in Kentucky, however, has enabled a closer look at the rocks and their stratigraphic relationships over a broad area, and has led to a redefinition of the Borden and some of its subdivisions (Weir and others, 1966; Sable and others, 1966; Weir, 1970; Kepferle, 1971). The Kentucky mapping has also led to a reinterpretation of some of the depositional environments for typical as well as unique units of the Mississippian sequence (Thaden and others, 1961; Sedimentation Seminar, 1969, 1972; Moore and Clarke, 1970; Peterson and Kepferle, 1970; Kearby, 1971).

In Indiana, stratigraphic relations of the upper part of the Borden have been restudied by Smith (1965). In Illinois, important contributions to interpretation of depositional environments in Borden equivalents have been made by studies of subsurface data (Swann and others, 1965; Lineback, 1966, 1968a, 1969). All of the above works contributed significantly to the conclusions of the present study.

Scope and method of investigation

The objectives of the study are to provide results of a modern sedimentologic investigation of the Kenwood and its associated units; particularly to determine their depositional environments and processes of sedimentation. Field observations and samples used in this study were obtained mainly during the geologic mapping of more than eleven 7-1/2-minute quadrangles in Kentucky as part of the geologic mapping program conducted jointly by the Kentucky Geological Survey and the United States Geological Survey (Peterson, 1966a, b, 1967, 1968, 1972; Kepferle, 1966, 1968a, 1969, 1972a, b, c). * Additional outcrops of the Kenwood were studied in Indiana in the Lanesville, Louisville West, Georgetown, and New Albany quadrangles. Borden outcrops were reconnoitered in the Borden and Speed quadrangles where the Kenwood is apparently absent.

* Field notes and traverse maps are on file with the Kentucky Geological Survey.

More than 25 stratigraphic sections were measured in detail through the Kenwood. Of these, only two include the total Borden Formation. In addition, more than 525 directional measurements and 892 thickness measurements were made from individual beds in the measured sections and from isolated exposures between sections. Observations of bedding types and bedding structures were made during this phase of the study. Forty-seven samples were collected for granulometric and thin-section analysis from 15 individual siltstone beds. Bulk X-ray analysis was made routinely of each sample studied petrographically as a check against possible discrepancies in microscopic mineralogic determinations. X-ray diffraction analysis of six samples provide data for describing the clay mineralogy of the shale interbeds in the Kenwood. A search for microfossils of potential value in age correlation proved fruitless. In summary, this is primarily a field study supplemented by judicious use of the laboratory.

STRATIGRAPHIC RELATIONS

The Borden Formation is a complex sequence of predominantly terrigenous clastics. In the central part of study area the sequence consists of the following members in ascending stratigraphic order: the New Providence Shale, the Kenwood Siltstone, the Nancy, the Holtsclaw Siltstone, and the Muldraugh Members. The Floyds Knob Formation as used by Stockdale (1939, p. 191-200) is herein called the Floyds Knob bed and is included as the basal part of the Muldraugh Member. In Kentucky the Borden rests mainly on the New Albany Shale, and in Indiana on the Rockford Limestone. The Harrodsburg Limestone overlies the Borden in the study area. (See fig. 3).

In a wider area, a somewhat more complicated stratigraphic picture arises, for some of the members intertongue with others into which they eventually disappear by gradation. The Kenwood Siltstone descends stratigraphically by intertonguing with the New Providence Shale Member; similarly, the Holtsclaw Siltstone Member descends within the Nancy Member, eventually grading into the Nancy (fig. 5).

The complications arising from this intertonguing are not reflected completely by the stratigraphic terminology. For, although all of the subdivisions are of equal rank within the Borden, the Kenwood and the Holtsclaw Siltstone Members are clearly less persistent and are more restricted areally than are the New Providence Shale, the Nancy, and the Muldraugh Members. It would be better perhaps to elevate the rank of the Borden to that of

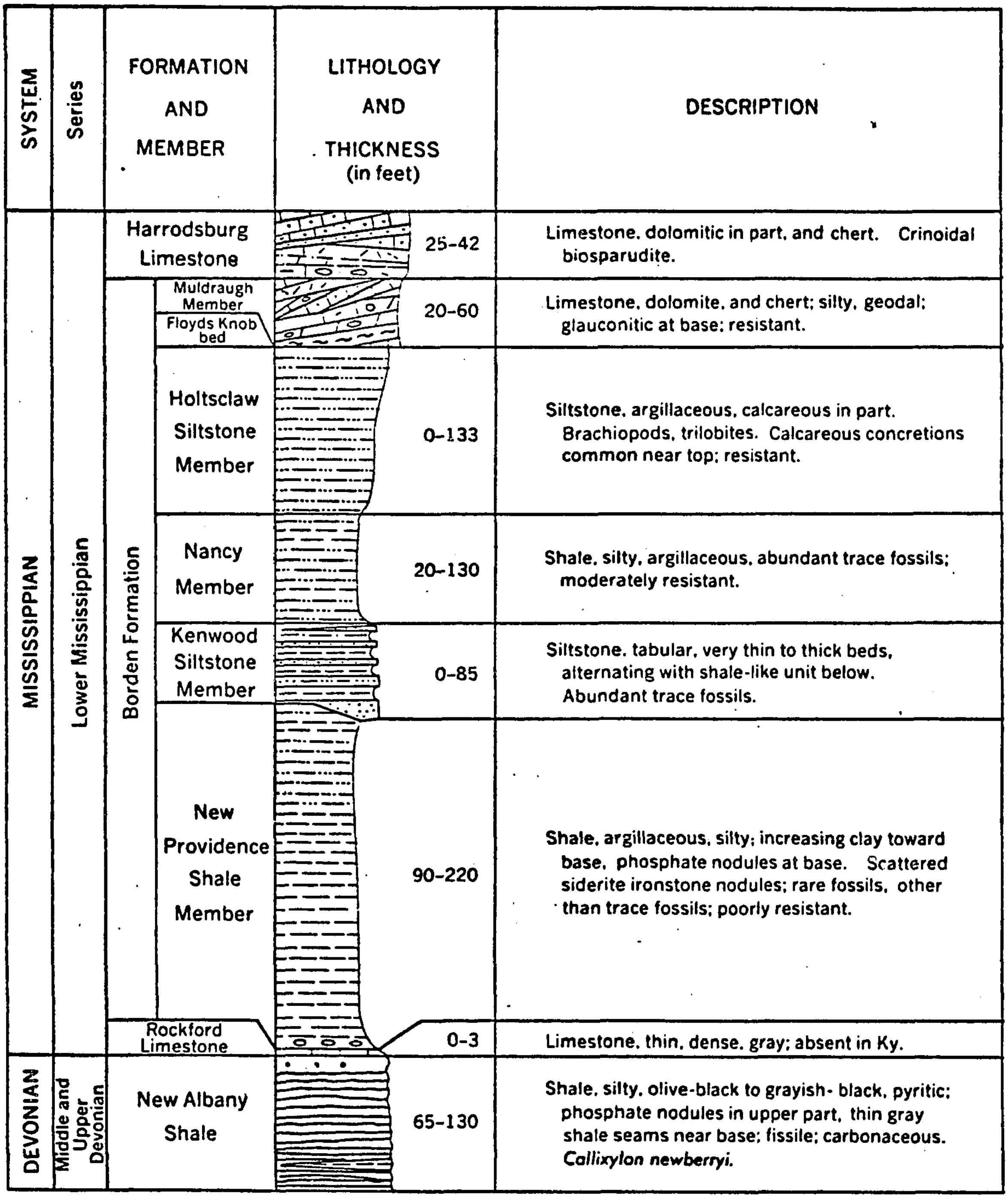


Figure 3. Generalized columnar section of the Borden Formation in north-central Kentucky.

a group as did Stockdale (1939), raising the more persistent subdivisions to formational rank and including the less persistent units as members of the appropriate formation. This practice would follow that of the Indiana Geological Survey and possibly would afford greater flexibility in future stratigraphic studies.

The Code of Stratigraphic Nomenclature, however, emphasizes that both formations and members must be mappable (Arts. 6d, 7b). The Code also stresses (Art. 6b): "Formations are the basic rock-stratigraphic units used in describing and interpreting the geology of a region." (American Commission on Stratigraphic Nomenclature, 1961, p. 650-651). For these reasons and because the units used in Kentucky correspond to those established in the current program of geologic mapping, rank changes are deemed inappropriate. Therefore, Kentucky usage is followed in this report (fig. 4).

The basis for the current rock-stratigraphic nomenclature for the subdivisions of the Borden Formation in the study area is the subject of a recent paper (Kepferle, 1971), included herein as Appendix B (in pocket). Some of the material therein is necessarily repeated in the following discussion of the stratigraphy of the Borden and the associated rocks.

The Borden Formation in most of the study area rests on the New Albany Shale, although in most of Indiana the two are separated by a single thin bed called the Rockford Limestone.

The New Albany Shale is olive-black to grayish-black silty shale that weathers pale yellowish brown or very light gray. It is

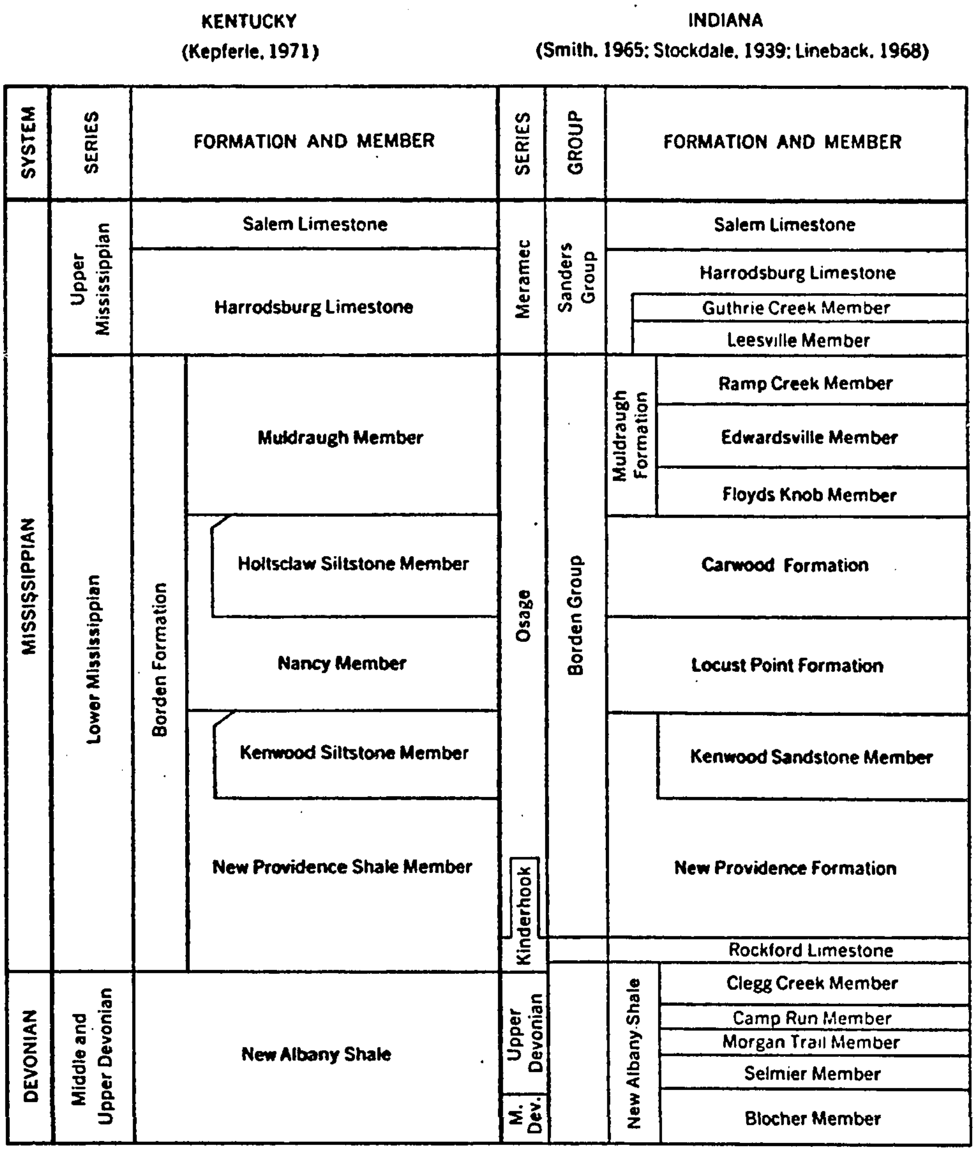


Figure 4. Comparison of stratigraphic terminology of the Louisville area, Kentucky, with that used in southern Indiana.

massive, brittle and dense where fresh and may fracture conchoidally, whereas weathering promotes disintegration into paper-thin chips along the bedding laminae. Phosphate nodules as much as 0.1 ft. (feet) across are common in the upper 10 feet; pyrite is abundant as spherules and veinlets; thin, interbedded gray shale is common near the base in beds as much as a foot thick. Lithostratigraphic subdivisions have been recognized in Indiana (Lineback, 1968b), but have not been mapped separately in Kentucky. The thickness of the New Albany Shale in outcrop increases from 55 feet in the southern part of the study area in Kentucky to more than 130 feet in the northern part of the area in Indiana. Common fossils include Tasmanites sp., conodonts, and silicified fragments of Callixylon newberryi logs as much as 5 feet long, on which crinoid remains have been found (Wells, 1941).

The Rockford Limestone is a greenish-gray, to olive gray, dense, ferruginous, dolomitic limestone that weathers orange-brown. It commonly occurs as a single bed, glauconitic and pyritic in part, at the base of the Borden. The Rockford has been believed to be restricted to Indiana (Reeves, 1922, p. 1067-1068). In 1971, however, the writer discovered two isolated exposures 5 miles apart in Louisville, Ky. The Rockford reaches a thickness of 2.5 feet in these exposures. Common fossils include scattered diminutive pelmatozoan remains and conodonts.

The New Providence Shale Member is the basal unit of the Borden in Kentucky and rests on the Rockford Limestone in Indiana.

It is mainly medium-gray to olive-gray silty clay shale which weathers to a light greenish gray or yellowish gray. In fresh exposures bedding is manifested by obscure laminations, and parting is commonly hackly and uneven to subconchoidal. Weathering enhances the incipient laminations and produces a secondary fissility, which may be lost through continued weathering. Abundant to rare siderite "ironstone" concretions locally stand out along some of the bedding planes. Minor constituents are rare phosphate nodules, and discontinuous thin beds and stringers of crinoidal limestone. Elongate to amoebiform phosphate concretions concentrated at the base of the New Providence in Kentucky are equivalent to the Falling Run bed of the Clegg Creek Member of the New Albany Shale immediately below the Rockford Limestone in Indiana (Lineback, 1968b, fig. 7). The thickness of the New Providence ranges from 90 to 220 feet in the study area. Fossils in the New Providence include brachiopods, crinoidal debris, bryozoans, small horn corals, auloporid corals, Foraminifera, and trace fossils. Biostratigraphic subdivision of the New Providence (Conkin, 1957) has no apparent lithostratigraphic basis.

The Kenwood Siltstone Member, which consists of interbedded siltstone and shale, overlies or locally intertongues with the New Providence Shale Member. The siltstone is medium gray, weathers to yellowish gray and is commonly iron-stained. The shale is similar to that of the New Providence. The thickness of the unit is generally less than 40 feet but locally exceeds 80 feet. Details of the Kenwood are discussed on pages 24 to 43.

The Nancy Member (Weir and others, 1966) directly overlies the Kenwood in easternmost exposures and to the west overlies the New Providence Shale Member (fig. 5). The Nancy is predominantly clayey silt shale which is olive gray to medium gray and ranges in thickness in the study area from 20 to 190 feet. The Nancy has not been recognized in Indiana, where equivalent strata include part of the Locust Point Formation and possibly some of the lower part of the Carwood Formation (fig. 4). Fossils in the Nancy include abundant "curly" trace-fossil markings along the bedding, and, in rare calcareous zones, crinoid columnals, bryozoans, and brachiopods.

The Holtsclaw Siltstone Member (Kepferle, 1971) overlies the Nancy Member in easternmost exposures and intertongues with the Nancy to the west in Jefferson and Bullitt Counties, Kentucky (fig. 5). As redefined, the unit has not been recognized in Indiana, but appears to be equivalent to the Carwood Formation (fig. 4). The Holtsclaw is medium-dark-gray to dark-gray siltstone that weathers olive gray to yellowish gray. The thickness of the Holtsclaw reaches about 130 feet. The grain size appears to be slightly coarser in the upper 20 feet. This part of the unit also shows extensive bioturbation, with abundant bedding-plane burrows and grazing trails. Brachiopods, gastropods, trilobites, and bryozoans are locally abundant, commonly as molds.

The complex of the Nancy and Holtsclaw members is everywhere overlain by a silty glauconitic zone here called the Floyds Knob

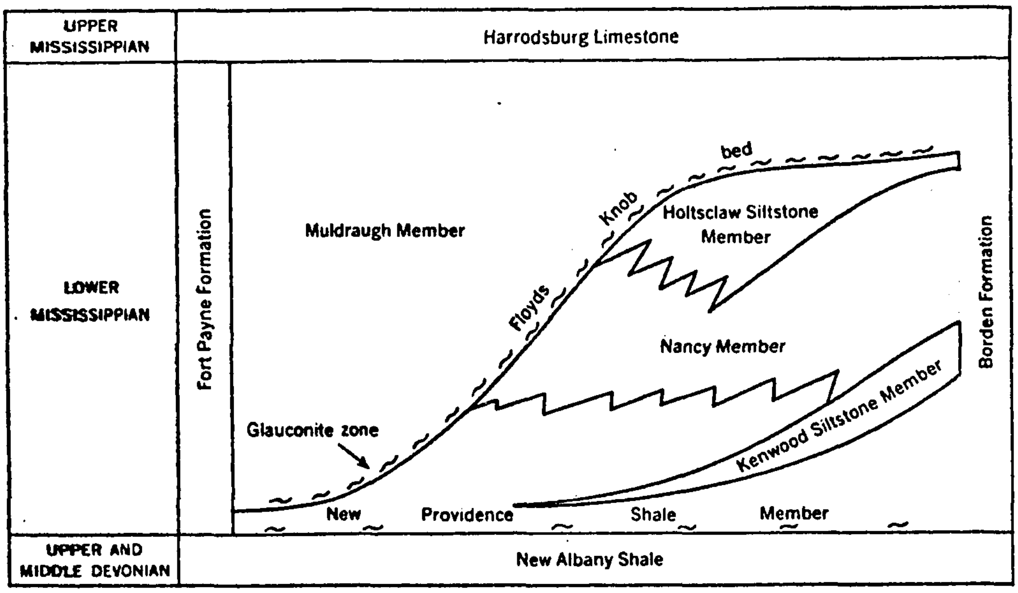


Figure 5. Diagrammatic cross section showing general relation of subdivisions of the Borden in the Louisville area to the Fort Payne Formation of central Kentucky.

bed. This zone is nearly everywhere marked by a conspicuous basal layer and a less prominent upper layer of greenish-black glauconitic silt. These layers locally coalesce but commonly are separated by as much as 18 feet of phosphatic siliceous silty dolomite, dolomitic siltstone, argillaceous siltstone, or brownish gray oölitic limestone. The zone contains abundant Foraminifera (Conkin, 1954, 1960) and locally abundant pelmatozoans, brachiopods and bryozoans. Stockdale (1939, p. 191) recognized this zone as "the most valuable key to the solution of several perplexing stratigraphic relations among the rocks of the upper portion of the Lower Mississippian column in Indiana and Kentucky". Confirmation of this statement was the discovery of the Borden delta front (Peterson and Kepferle, 1970), discussed below. Because this glauconitic zone is everywhere thin it has been included for the most part with the Muldraugh Member for mapping purposes.

The Muldraugh is the uppermost member of the Borden in the area. In the vicinity of Louisville it consists of olive-gray to medium-dark-gray dolomitic siltstone and silty dolomite that weather yellowish gray to light olive gray and are complexly interstratified with medium- to light-gray, coarse crinoidal limestone. Chert and siliceous geodes are common and locally accentuate a knotty mottled appearance of the irregular bedding. The thickness in the study arearanges from 20 feet to 60 feet. Bryozoans, crinoid columnals, and scattered brachiopods are locally common.

Lack of detailed mapping in the Indiana portion of the study area precludes a complete understanding of the stratigraphic relationship of the Edwardsville (fig. 4), which is included as a member of the Muldraugh Formation by Smith (1965). In a section measured west of New Albany, the Edwardsville consists of 52 feet of dolomitic siltstone and silty shale. The siltstone is light gray and weathers dark yellowish brown in even, continuous beds which generally are less than 0.5 ft. thick. The resistant, rib-like siltstone is restricted to the upper half of the unit. The shale is the same color as the siltstone, but is less resistant and the beds, where interbedded with siltstone, are commonly greater than 2 ft. thick. Obscure cross lamination and planar, horizontal laminae characterize the siltstone beds, some of which show trace fossils and load casts on well-defined bases. In stratigraphic position and lithology, the siltstone of the Edwardsville most resembles the "Rockcastle freestone" of the Wildie Member of the Borden in the Berea area of Kentucky (Weir, 1970).

The Harrodsburg Limestone overlies the Borden over a broad area in southwestern Indiana and west-central Kentucky. The Harrodsburg is a sparsely-glauconitic, light-gray to light-olive-gray crinoidal limestone with a matrix that ranges from sparry clear crystalline calcite to micritic calcite. The unit is thin bedded and cross bedded. Scattered grains of glauconite and the sparry matrix of the Harrodsburg serve to distinguish it from the crinoidal limestones of the underlying Borden Formation. The

Harrodsburg Limestone ranges in thickness from 25 to 42 feet in the study area. Common fossils include brachiopods, bryozoans, horn corals, blastoids, and abundant crinoidal debris. The persistent character of the relatively thin Harrodsburg is in marked contrast to the variations in lithology characteristic of the underlying Borden Formation over the same area.

A few miles southwest of the western extent of the Kenwood is a change in the lithology of the Borden Formation. This change is marked by an incomplete termination of the predominantly terrigenous clastic siltstone and shale facies that constitute the main part of the Borden to the north and east, and by a reciprocal southwestward increase in thickness of the dolomitic, calcareous, siliceous facies characteristic of both the Fort Payne Formation and the Muldraugh Member of the Borden (fig. 5). This change has been delineated in outcrop by geologic mapping, summarized for the outcrop area by Peterson and Kepferle (1970, fig. 4), who call it the "Borden delta front". The strike of the front (fig. 6) has been projected in subsurface to the northwest into central Indiana, where it coincides with the 100-ft. isopach line of the Borden siltstone delta of Swann, Lineback, and Frund (1965), and, on the basis of mapping, appears to extend southeastward at least as far as Pulaski County, Ky. (Lewis, 1971). The relationships thus outlined have a direct bearing on the environment of deposition of the Kenwood Siltstone Member--a subject discussed more fully following a detailed examination of the Kenwood.

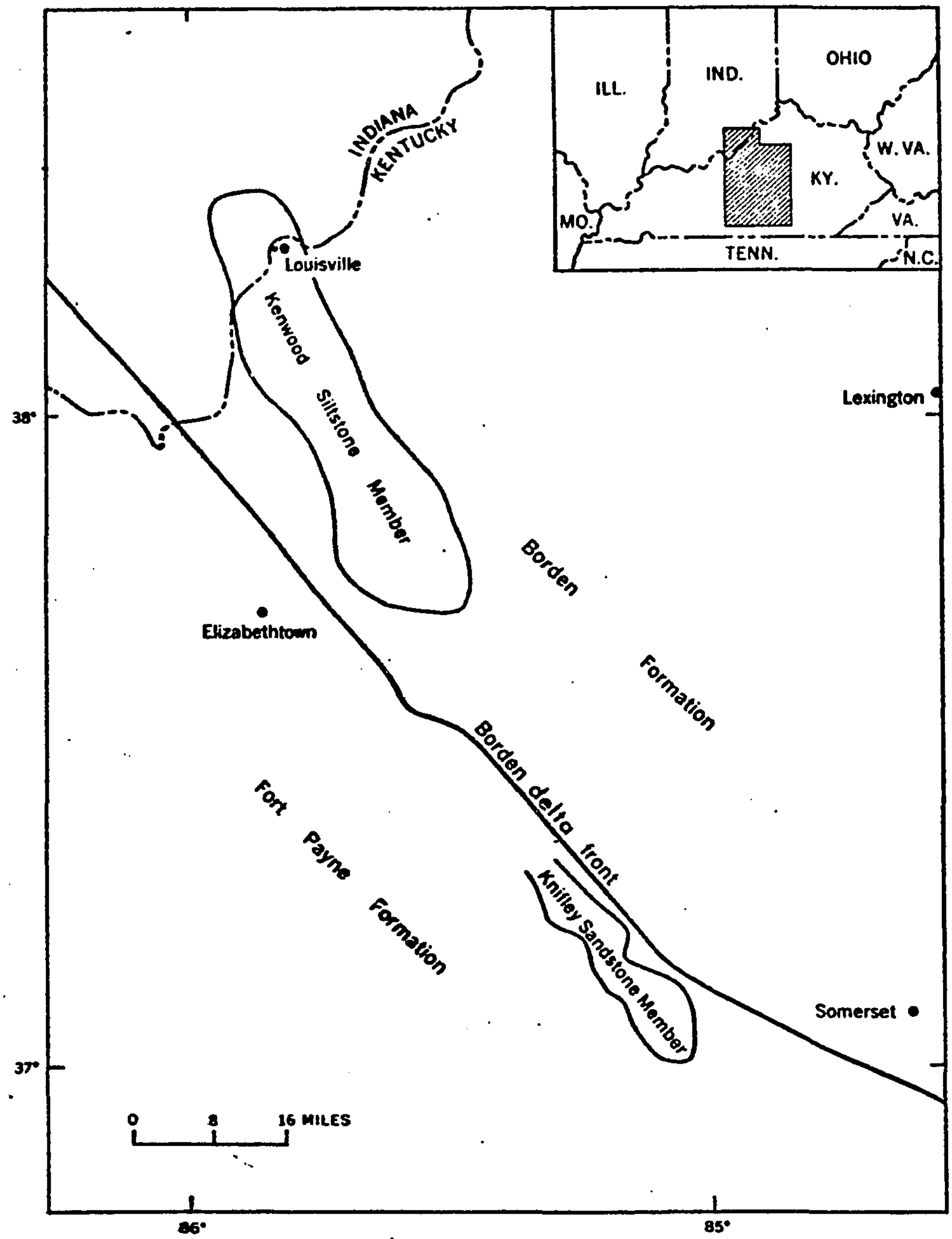


Figure 6. Areal relationship of Borden delta front to the Kenwood Siltstone Member of the Borden Formation and the Knifley Sandstone Member of the Fort Payne Formation.

STRATIGRAPHY OF THE KENWOOD SILTSTONE MEMBER

The Kenwood was named by Butts (1915, p. 148) for exposures on Kenwood Hill in the southern part of the city of Louisville, Jefferson County, Kentucky. Although he believed the unit was consistently 40 feet thick in Jefferson County, the completion of the geologic mapping along most of the Muldraugh Escarpment in Kentucky has shown that the thickness of the Kenwood may locally exceed 80 feet. This mapping has also shown that the resistant beds for which the unit is named are siltstone rather than sandstone. Stockdale (1939, p. 109-111) included the Kenwood as the uppermost member of the New Providence and, although he recognized that the interval between the top of the Kenwood and the base of the New Providence decreases from north to south, he did not recognize the magnitude of this decrease. Nor did he recognize that the Kenwood extends southward, beyond the limit of the exposures along the escarpment in the vicinity of Shepherdsville, Bullitt County, Kentucky, into the Knobs. This is clear from his description (1939, p. 113), of the New Providence in Nelson County:

> "In western and southwestern Nelson County there occur, 25 to 40 feet above the base of the New Providence shale, fine-grained sandstone (siltstone) layers in smooth beds, from a few inches to 4 feet thick in thickness, separated by sandy shale partings. The best exposure observed by the writer is along U. S. Highway No. 62, half a mile

southest of Boston commencing 25 feet above the base of the formation. These fairly soft yellow-buff beds may at first be confused with the Kenwood member farther north, on the basis of lithology. Field data, however, show them to be stratigraphically much lower and to be overlain as well as underlain by typical New Providence shale."

The Kenwood is now known to include these beds and to extend a few miles south of the exposure described above.

Siltstone beds are characteristic of the Kenwood, even though these beds constitute less than 50 percent in more than two-thirds of its extent. Continuous exposures of individual beds are rare. Complete vertical exposures in which all beds appear are likewise rare. Significant exposures, for which complete sections of the Kenwood are described herein (Appendix A) are shown on the map (fig. 7).

The siltstone, where freshly exposed, is medium gray to medium dark gray; where weathered it is medium light gray to light olive gray or yellowish gray, and is commonly limonite stained to a dark yellowish orange.

The shale interbeds of the Kenwood, although they are the dominant lithology, do not differ from the shale of the New Providence except for the siltstone beds which separate them. These shale interbeds are dark greenish gray, dark to medium gray, olive gray to grayish green where fresh and weather yellowish gray to light greenish gray. They are moderately to poorly indurated,

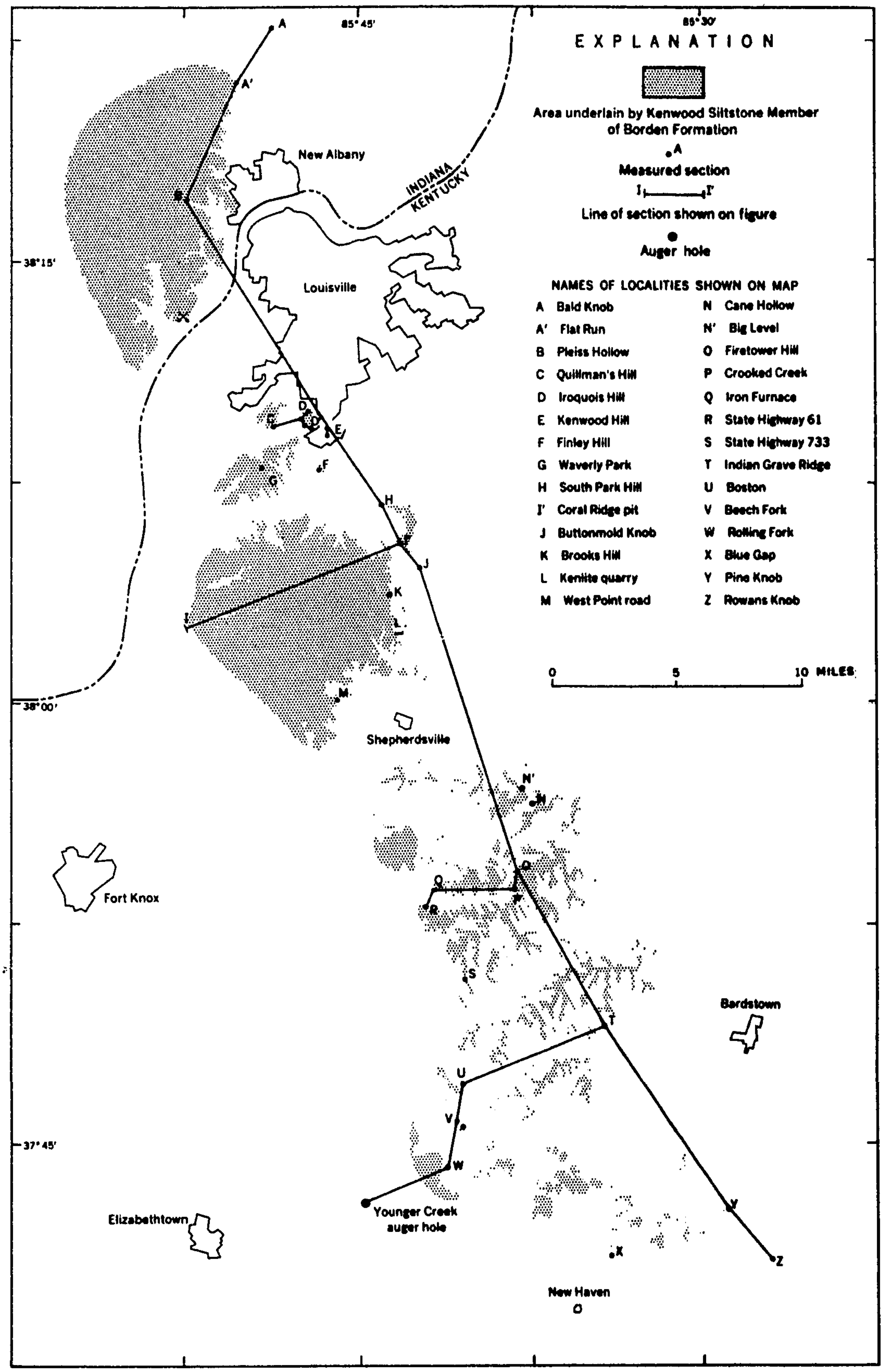


Figure 7. Area underlain by Kenwood Siltstone Member of Borden Formation showing lines of section shown in fence diagrams, figs. 5, 13, and 14.

silty, micaceous and contain local concentrations of sideritic ironstone concretions in layers that are common along the otherwise obscure bedding planes.

Bedding

Geometry and facies distribution are significant factors in determining the depositional environment of the Kenwood. Geometry of the Kenwood is shown by isopach maps of the total thickness of the Kenwood (fig. 8), the interval between the base of the Kenwood and the base of the Borden Formation (fig. 9), and the summation of these two intervals (fig. 10). The geometry and abundance of contained siltstone is shown on maps of the areal variations of the siltstone component expressed as the siltstone-to-shale ratio (fig. 11), and the thickness of the thickest siltstone bed (fig. 12).

The Kenwood is thickest in two areas along the eastern margin of the study area (fig. 8). The thicker of these areas lies in the eastern part of the Shepherdsville quadrangle, Bullitt County, Kentucky, where the Kenwood is 82 feet thick. The other is north, in Brooks and Louisville West quadrangles, Jefferson County, Kentucky where the Kenwood is 65 feet thick. The other thickness parameters on figures 9, 10, and 12 similarly are high in the east and low in the west even though the easternmost sections commonly are incomplete owing to truncation during the present erosion cycle. An abnormally thick bed in the southwestern part of the area is an

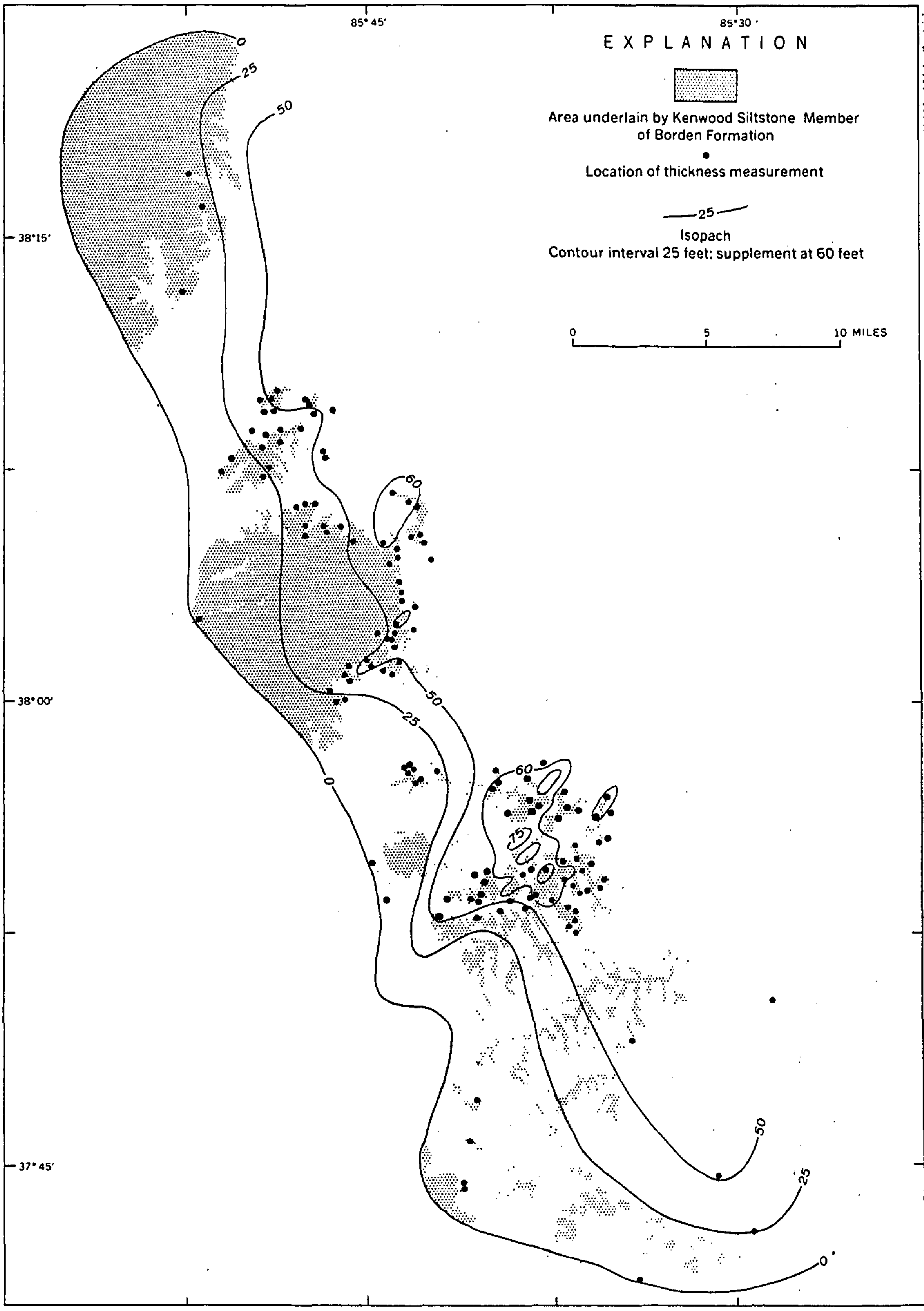


Figure 8. Isopach map of the Kenwood Siltstone Member.

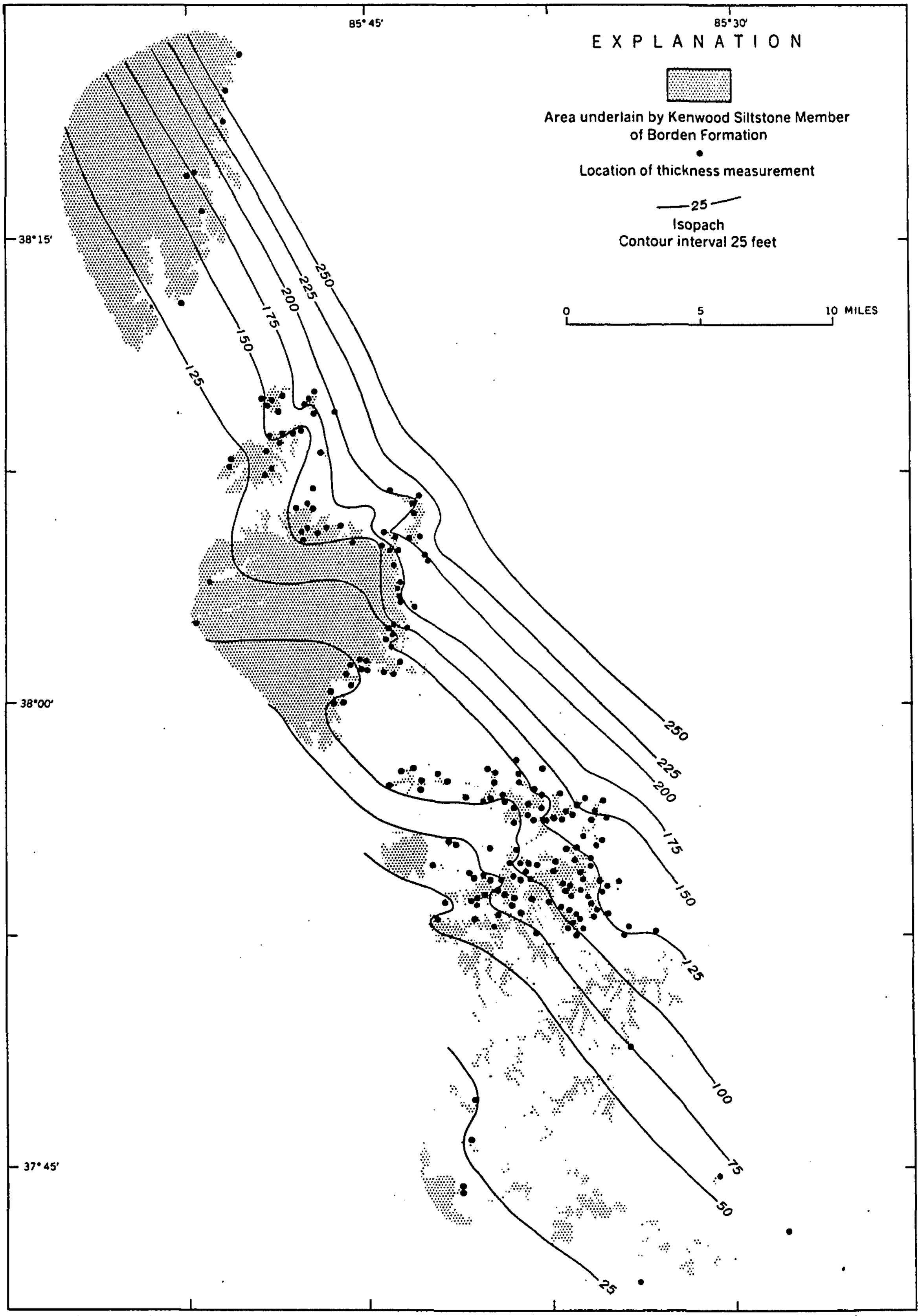


Figure 9. Isopach map of the interval between the base of the Kenwood Siltstone Member and the base of the Borden Formation.

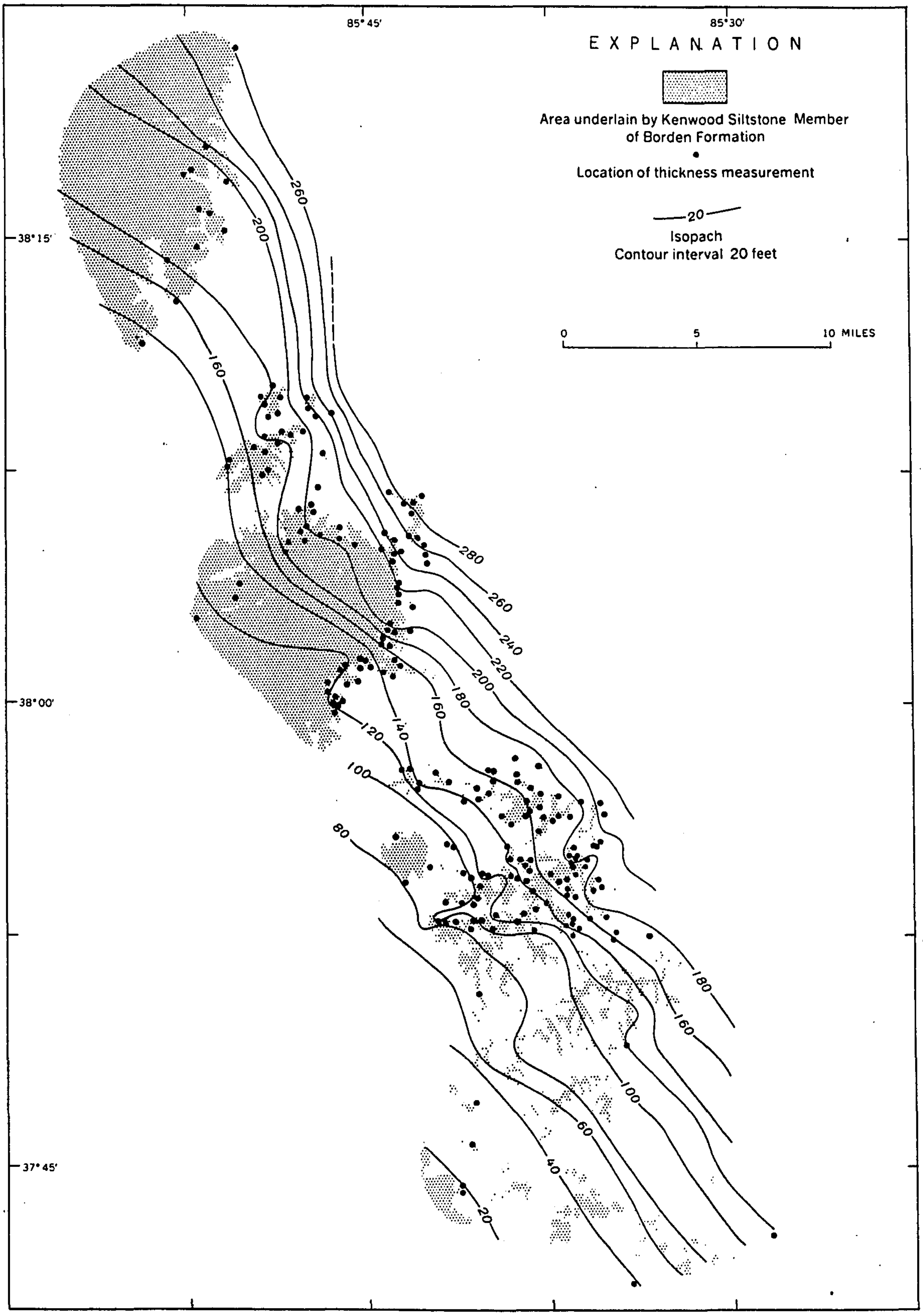


Figure 10. Isopach map of the interval between the top of the Kenwood Siltstone Member and the base of the Borden Formation.

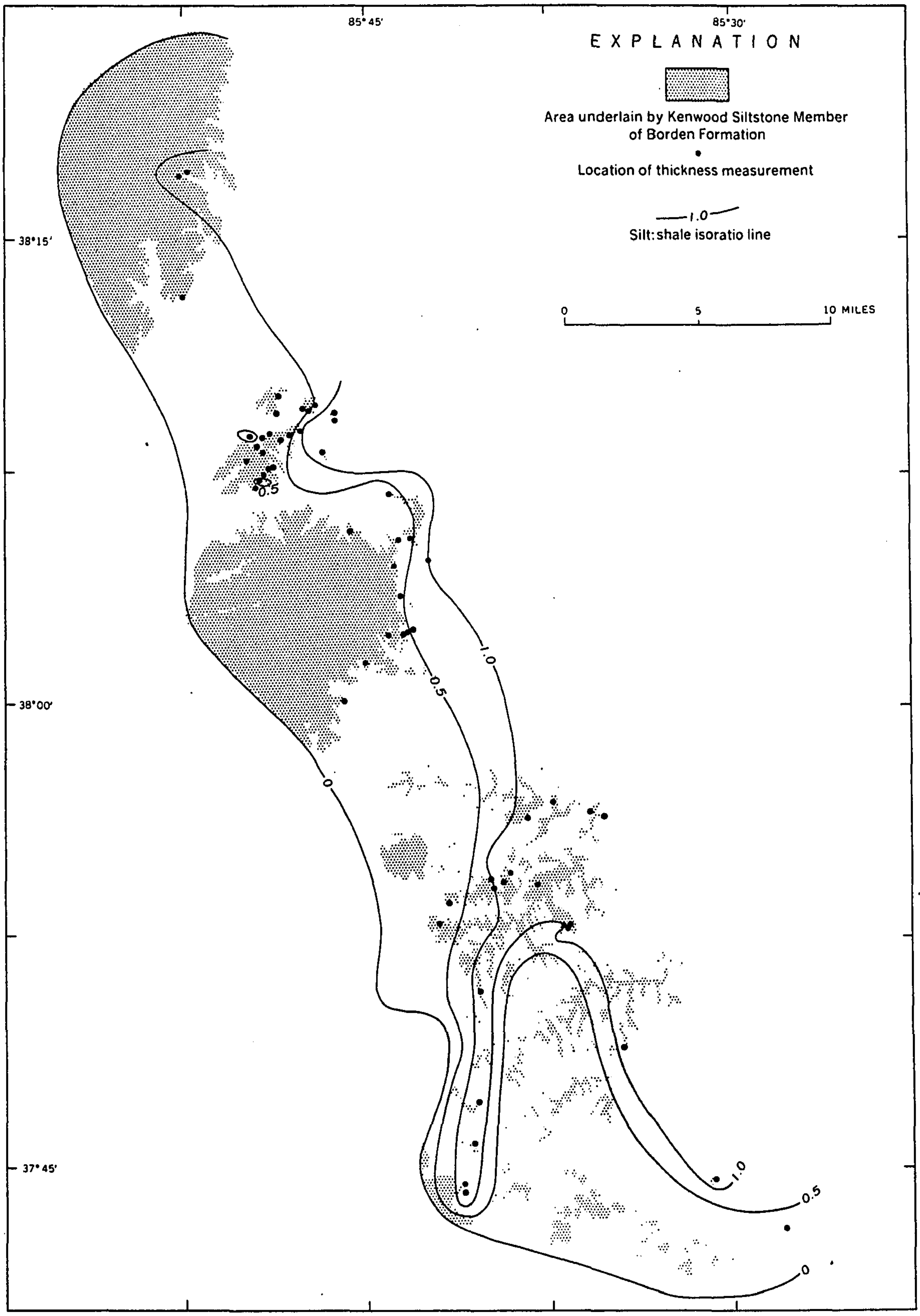


Figure 11. Facies map of the siltstone:shale ratio of the Kenwood Siltstone Member of the Borden Formation.

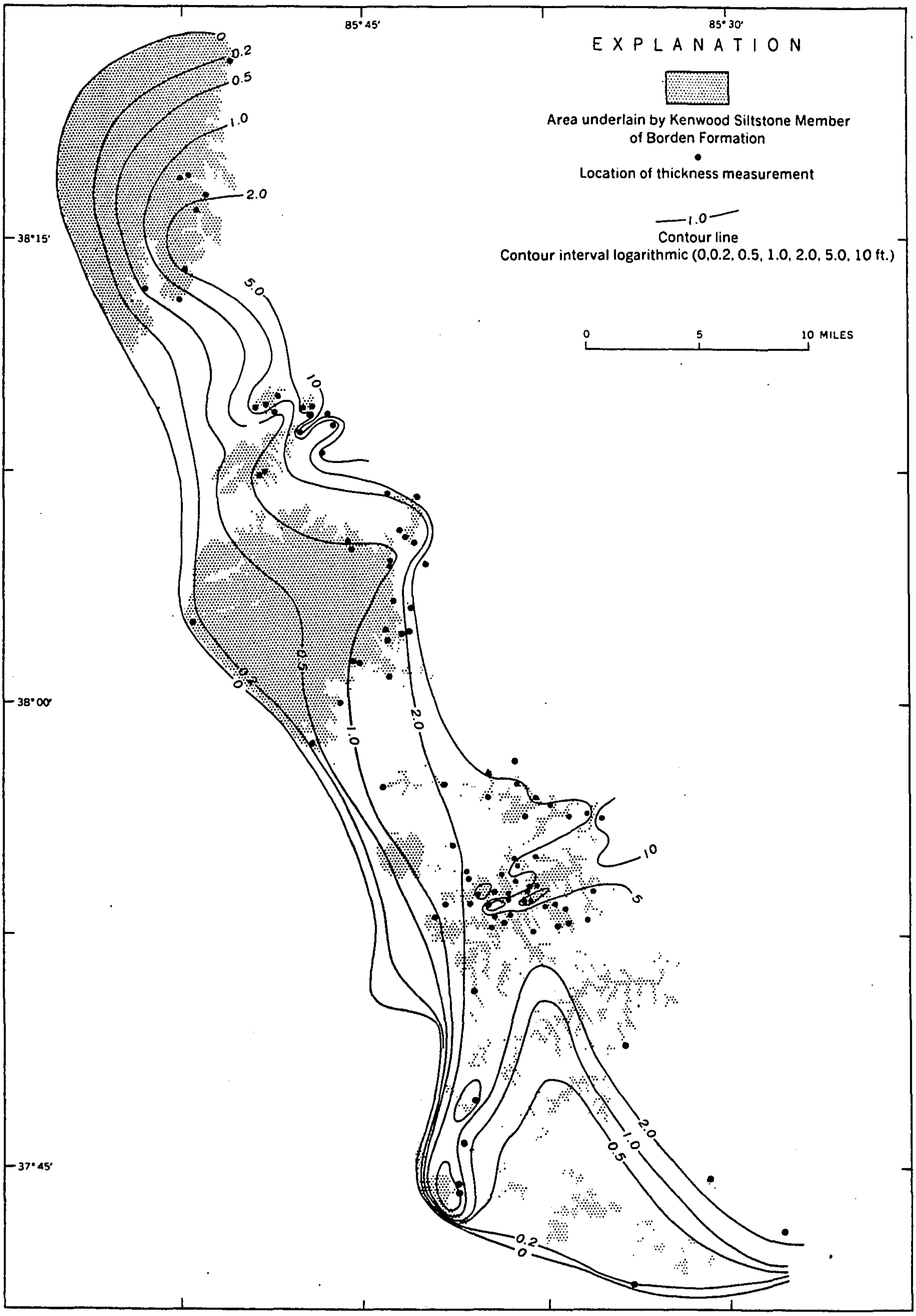


Figure 12. Isopach map of thickest siltstone bed in the Kenwood Siltstone Member of the Borden Formation.

exception to the general pattern.

Dip

At most localities, the beds appear flat-lying. Mapping has shown, however, that they descend westerly through the lower part of the Borden Formation. This depositional dip is 5 to 20 feet per mile relative to the base of the Borden, and is superimposed on a structural dip that is 40 to 60 feet per mile to the west (fig. 14). The overall dip of individual beds in the Kenwood is from 45 to 80 feet per mile to the west-southwest (less than 1°). Anomalous dips of from 3° to 10° at four localities are attributable to deposition associated with channel-filling. At two of these localities the channels have been traced in the field with limited success.

Thickness

The thickness of the individual siltstone beds in the Kenwood is fairly persistent for a given exposure. The bed thickness ranges from less than 0.1 to 20 feet. The thicker beds are generally found in the eastern-most area of outcrop (fig. 12). Exceptional examples of extreme thickness variations in distances of less than half a mile are found on Kenwood Hill, in Bernheim Forest, in Kenlite quarry and along the Rolling Fork (pl. 1). In most of these instances the thicker beds are related to possible channel fills where some beds may be composites of two or more beds.

Bed thickness is considered by many to be log-normally

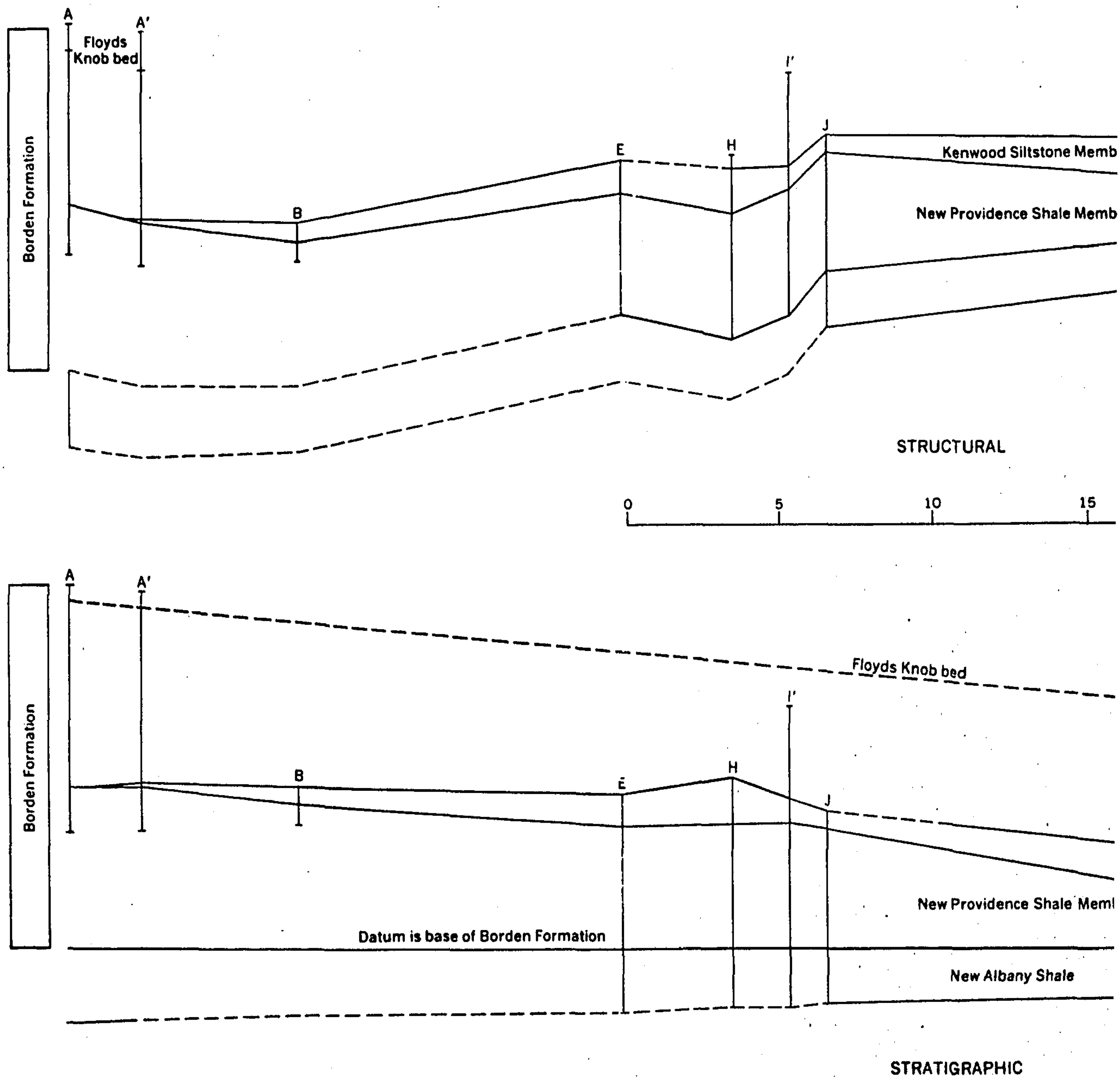
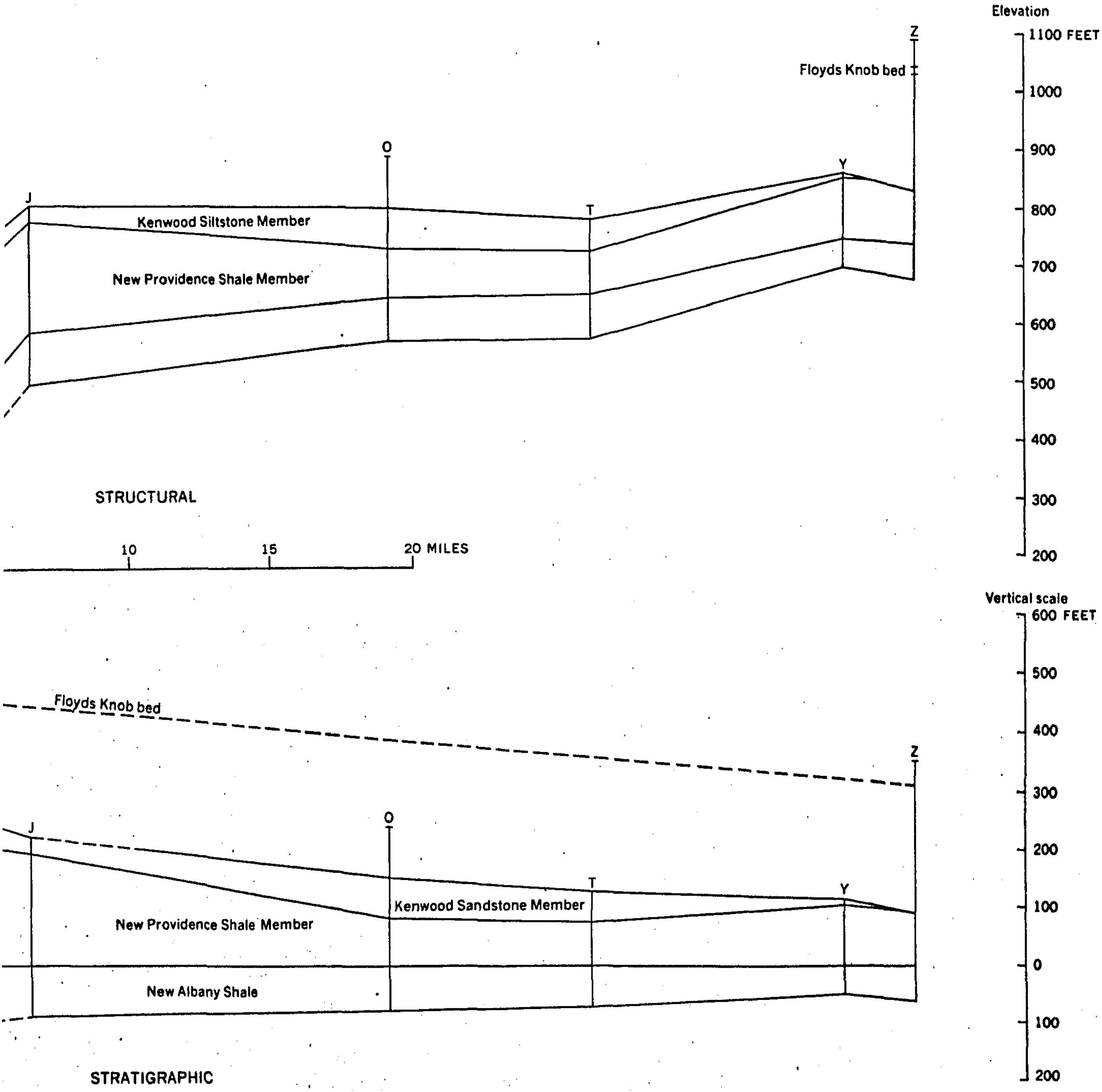


Figure 13. Fence diagrams of the Kenwood Siltstone Member of the
Location of sections shown if figure 7.



tone Member of the Borden Formation.
ure 7.

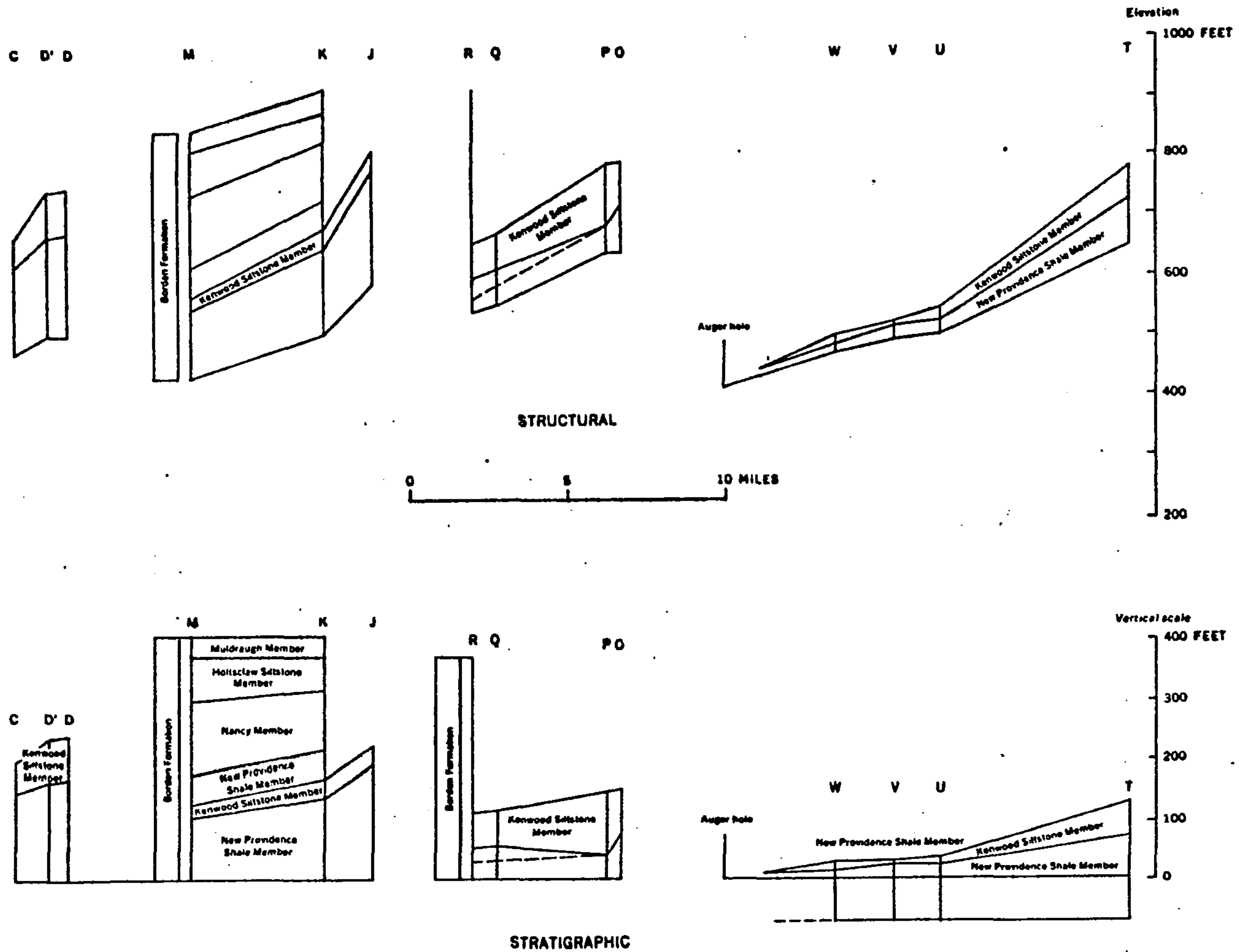


Figure 14. Fence diagrams of the Kenwood Siltstone Member of the Borden Formation. Location of sections shown on fig. 7. Dashed line in section RQPO is horizon of sideritic "ironstone".

distributed (Pettijohn, 1957; Bokman, 1957; Nederlof, 1959; McBride, 1962; Scott, 1966; Hubert, 1967). A distribution that is not, strictly speaking, log normal is reported by Enos (1969, p. 705-706), who maintains that logarithmic treatment of the bed thickness data is justified by a significant correlation between grain-size and bed-thickness expressed logarithmically.

A graphic method is used herein for determining the thickness parameters of log normality for the siltstone beds of the Kenwood. The cumulative percent of beds thinner than a given 0.1-foot interval is plotted on arithmetic probability paper superimposed on a logarithmic scale so that four class intervals on the arithmetic probability scale lay between powers of ten on the logarithmic scale (fig. 15). The resultant curve was used to determine statistical parameters in much the same manner recommended by Folk (1968, p. 44-50) in determining grain size parameters from size analyses. Without further statistical treatment, the linearity of the plot indicates an approach to log normality of the thickness of the siltstone beds.

The disparity between the arithmetic and logarithmic statistical values can be seen in the clustering of data points near the center of the probability scale. Modal thickness in 0.1-foot increments is near 0.25 foot, whereas parameters determined from the logarithmic treatment of data show a graphic median thickness of 0.55 foot, a graphic mean thickness of 0.71 foot, and a graphic standard deviation of 2.26 of the individual class interval on probability paper. Even so, graphic skewness of the curve for the

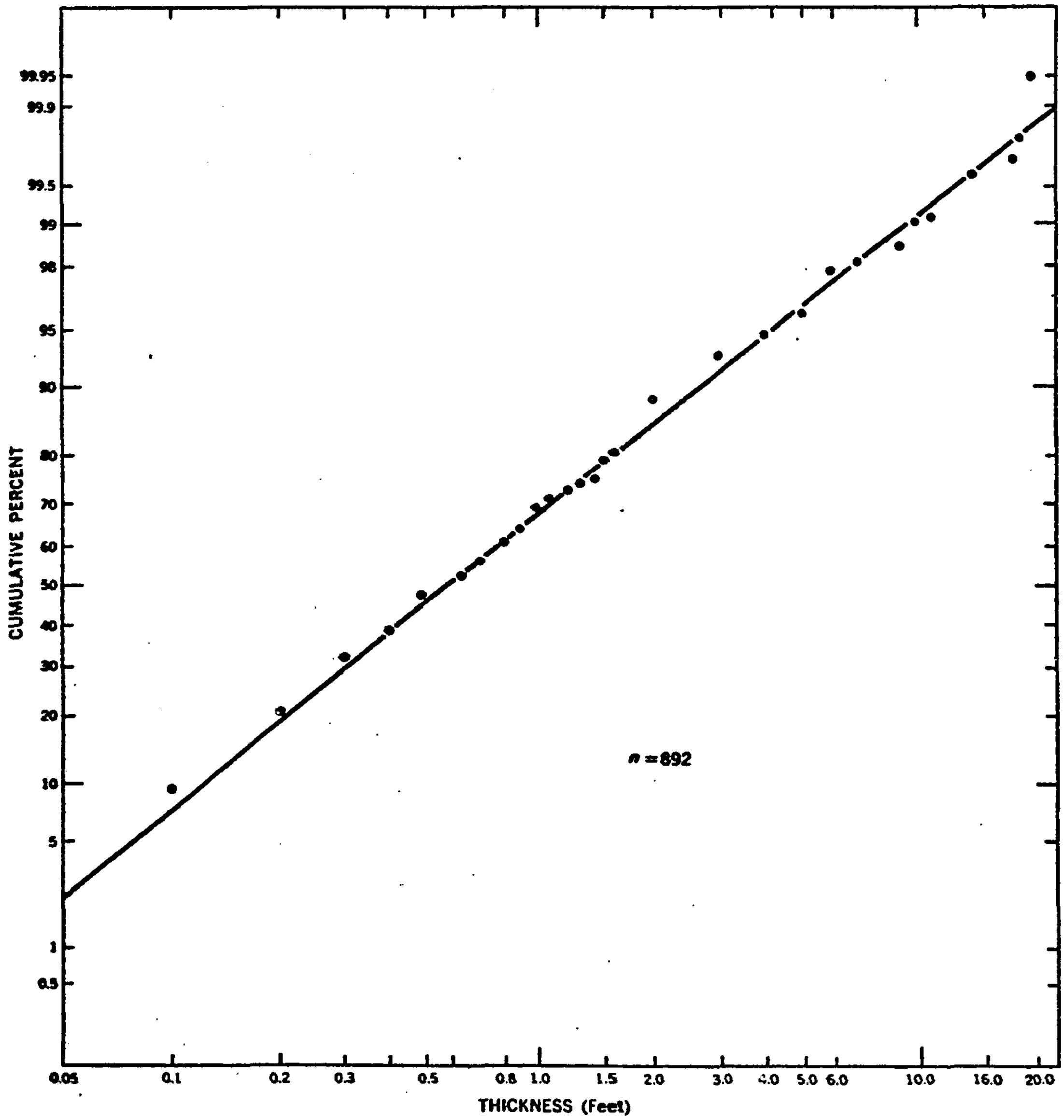


Figure 15. Cumulative curve showing thickness distribution of siltstone beds in the Kenwood (arithmetic probability paper with thickness on a logarithmic scale).

entire population is +.116 (nearly symmetrical to thick-skewed); the graphic kurtosis is 0.90, or mesokurtic. These last two parameters tend to reflect the linearity of the plotted data and the log-normality of the bed thickness data.

Some of the measurements used in the compilation may introduce more bias than others. For the measured sections only one thickness measurement per bed section permitted the least inherent bias. Other data used, however, include non-selective observations "of opportunity" obtained during mapping. For these data, possible bias is introduced because of incomplete exposures and because the more prominent beds are more visible on an outcrop. These factors eliminate thinner beds from consideration. Thicker beds, too, might be eliminated from consideration because they are rarely completely exposed. In essence, selective observations are less likely to include representative samples of the tail elements of the thickness curve than are comprehensive observations made in the course of measuring a detailed section.

Channel-fill beds

The possible channel-fills in which the thicker siltstone beds of the Kenwood are found can be subdivided into three types. These types are based in part on size and in part on the geometry of the siltstone beds that make up the fill. The simplest form, type I, is shallow, narrow, and restricted to a single bed, the top of which is planar (fig. 16a). The type II channel is filled with beds that appear to be thicker than beds in adjacent outcrops; the tops of the beds in type II channels are planar, and the channel contains more than one bed (fig. 16b). The most complex form of channel-filling, type III, consists of several inclined siltstone beds that tend to coalesce towards the center of the channel (fig. 16c). Common to all the channel-fills is an absence of sole marks on the basal beds. The reason for this is not clear, but it may be that the current responsible for scouring the channel was sufficiently dense and sufficiently rapid to produce scour under plane-bed conditions of the upper flow regime (fig. 33).

The three types of channel-fills are believed to represent, from type I to type III, an increase in the magnitude and variability of the currents associated with their deposition as well as the magnitude of the current responsible for the original channel. The type I channel represents minor erosive power of the current preceding deposition, and the lack of persistence of this directed current is reflected by the absence of any similar influence in the overlying beds. The types II and III channels, on the other hand, by their depth reflect considerably more initial erosive scour from the currents preceding deposition. Type II channel-fills appear to

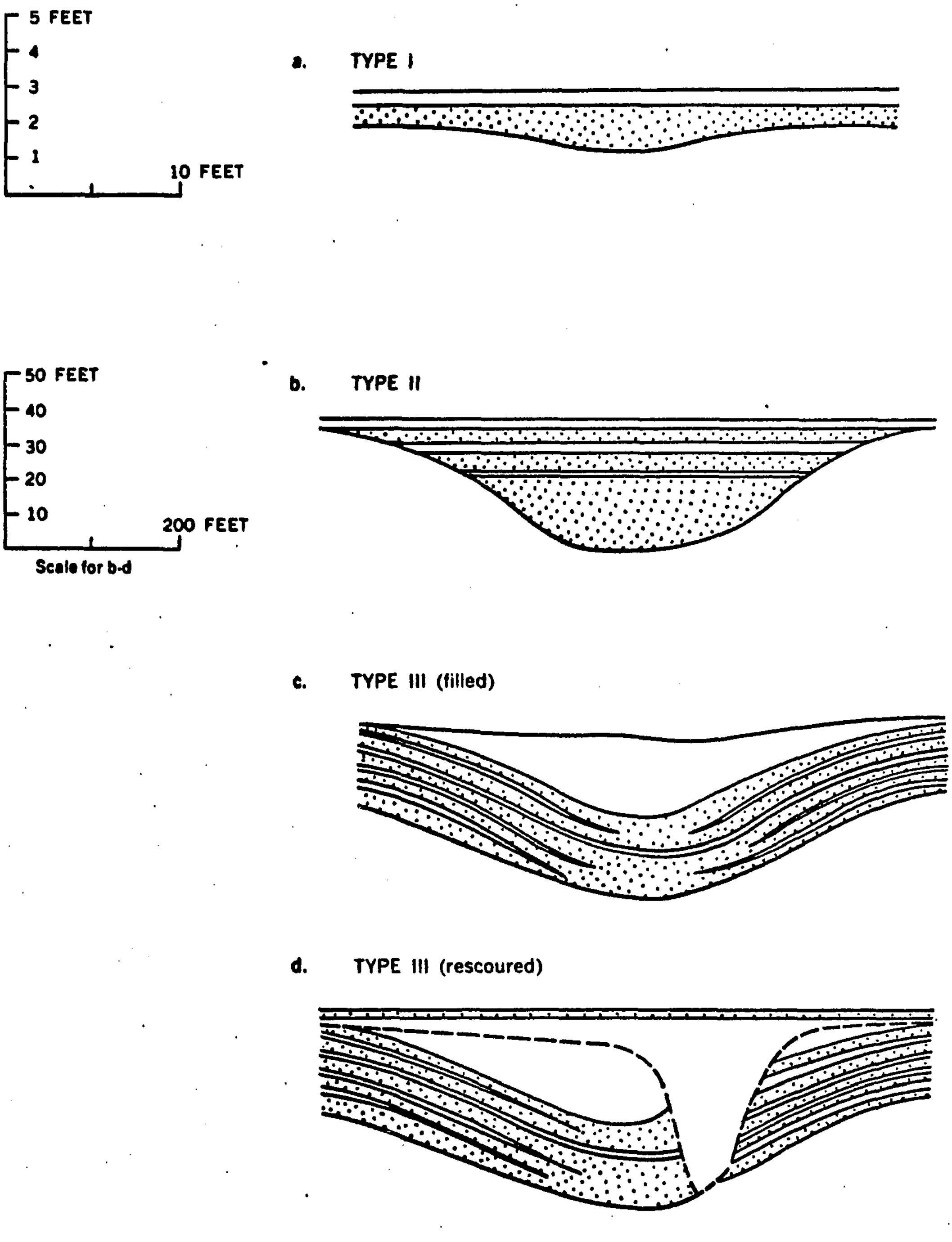


Figure 16. Channel-fill types in the Kenwood Siltstone Member of the Borden Formation.

have been deposited from currents confined to the channels, inasmuch as these beds are characterized by horizontal tops. Type III channel-fills, however, appear to have a far more variable sequence of deposition than either of the other two types. Type III fills appear to have been the result of alternating scour and deposition: scour following period of mud accumulation could have removed incompletely the mud from the top of the underlying silt layer so that the subsequently deposited layer of silt appears to coalesce with the underlying silt layer. Repetition of this process could eventually lead to a filling of the channel. If the current from which the siltstone beds were deposited were not confined to the channel, a drape effect of the subsequent silt deposit could result in initial dips of as much as 10° within a channel. Should a current reoccupy a partially filled channel, it might scour anew some or all of the silt deposits and repeat the depositional process or abandon the channel to pelitic accumulation (fig. 16d).

A pelitic clay-shale fill in a scoured type III channel seems to account for the depositional features in the channel along the boundary between Samuels and Shepherdsville quadrangles (loc. N, fig. 7; pl. 1). A noteworthy example of a type I channel fill can be found along the private road leading up the northwest end of South Park Hill in Jefferson County, Ky. A type II channel fill lies a fourth of a mile south of the lookout tower in Bernheim Forest, Bullitt County, Ky. These three types of channel-fills will be reconsidered in the discussion of the origin of the Kenwood.

Bed distribution in vertical section

Siltstone beds in the Kenwood may occur singly or in bundles of several beds. Such bundles maintain continuity over a greater distance than do individual beds, and thus are useful markers in mapping the Kenwood. Thomson (1971) recently described bed "packages" in the Ventura basin, California, according to the arrangement of thick and thin beds in the package. His Class I packages are those where the thicker beds, possibly composite beds, appear in the base of the package. His Class II packages contain the thicker composite beds in the middle of the package, and his Class III packages contain mainly separate individual beds. These classes can be applied similarly to the Kenwood bed bundles. Class I appears in a narrow band on the east margin of the area of outcrop. Class II bundles appear just to the west of this band, and, with few exceptions, Class III bundles include the remainder and largest part of the area.

The number of beds in a vertical section varies in a regular pattern from east to west just as do the bedding packages of the Thomson (1971) classification: the number of beds is greater in the easternmost belt of outcrops than in the remainder of the area. Too few complete sections are known to enable showing an isopleth map of the number of siltstone beds present within a continuous vertical section of the Kenwood. The unit commonly contains from 6 to 8 siltstone beds, but a wide range of variation from this norm is apparent. At the feather edges, the Kenwood is a single siltstone bed; at exceptional localities such as on the south end of Indian Grave Ridge in Nelson County at least 37 individual beds are recognized (loc. T, fig. 7).

Siltstone content

The total thickness of siltstone in the Kenwood was determinable at only a few localities. Measured partial sections were used in computing the present siltstone present as well as the sandstone-shale ratios in the Kenwood. This procedure follows that of Lovell (1970) in his study of the Aberystwyth Grit, in which he decided that partial sections are valid bases for thickness, sand-shale ratios, and percent sandstone beds. His partial sections, however, contained more beds than generally occur in the entire Kenwood, whereas the present study uses as few as two siltstone beds in computing siltstone-shale ratio for inclusion on the map (fig. 12). By contouring the higher values, a definite pattern evolves showing a decrease in siltstone content from east to west. This procedure may be questioned from the same standpoints of exposure and selection as were brought out in the discussion of bed thickness measurements, but the trends are believed to be valid.

PETROLOGY

The Kenwood Siltstone Member of the Borden Formation consists of two major lithologies: siltstone and shale. Analyses of the composition and texture of these lithologies provide the basis for determining provenance and environment of deposition, and for comparison with other units in the Borden. A comparison of textural parameters and composition of the Kenwood with those of other members of the Borden Formation or related rocks may furnish additional clues to the origin of the Kenwood or of the Borden as a whole. With this in mind, additional studies were made of samples (1) of the Borden rocks similar to the Kenwood in external appearance, (2) samples of the Borden above the Kenwood, and (3) samples of a unit in the Fort Payne Formation. In the first category are samples of the Farmers Siltstone Member and of the "Rockcastle freestone" beds of the Wildie Member of the Borden; in the second category are samples of the Holtsclaw Siltstone Member of the Borden, and in the third category are samples of the Knifley Sandstone Member of the Fort Payne Formation.

The Kenwood samples studied petrologically represent two main areas. One of these is the Kenwood type section on Kenwood Hill Jefferson County, Ky. (loc. E, fig. 7); the other is to the south in the Shepherdsville area of Bullitt County, Ky.

Composition

Both the siltstone and shale of the Kenwood consist of framework and matrix components. The distinction between the two lithologies is based on the relative abundance of the two components: the framework constituents are more abundant in the siltstone, whereas the matrix components are more abundant in the shale. Hence, the siltstone was sampled for identifying the framework constituents, and the shale was sampled for identifying the clay matrix.

Siltstone

Composition of the siltstone of the Kenwood Siltstone Member of the Borden Formation was studied in 46 thin-sections of samples from 15 beds. Most beds were sampled at the top and base, and additional samples were taken from within some of the thicker beds. Mineral composition as percentages of framework grains and matrix was determined from 300 point counts per thin section. As a check, qualitative minerology was determined by X-ray diffraction.

The major framework constituents in thin sections of the siltstone range from 49 to 80 percent and average 68 percent, and consist chiefly of quartz, feldspar, and rock fragments. The percent matrix ranges from 11 to 52 percent and averages 28 percent. The matrix consists chiefly of sericitic illitic clay, limonite, and microcrystalline quartz. The matrix is obscured in fresh samples by calcite and/or pyrite cement. The individual components of the framework were recalculated to 100 percent on a matrix-free basis. Mica is conspicuous in most beds but was not included in the framework calculations. Data for individual samples are shown in table 1 and summarized in pie diagrams (figs. 17 and 18).

Quartz constitutes 54 to 93 percent of the framework grains. Three main types were identified: plain quartz (71 percent), polycrystalline quartz (21 percent), and undulose quartz (8 percent). Some of the quartz grains show overgrowths in the form of "fuzzy" rims, but overgrowths otherwise are not obvious in thin section. Evidence for diagenetic silica cementation, however, was found during binocular examination (at 60X magnification) of samples during disaggregation for textural analysis: some of the aggregates appeared to be radiating from centers cemented with microcrystalline quartz. Minor bubble trains, reddish tetragonal crystallites, and rutile (?) needles occur in some of the quartz grains.

Feldspar, second most abundant constitutent, comprises from 5 to 36 percent of the framework grains. Potassium feldspar (95 percent), plagioclase (5 percent), and a trace of microcline were identified. Differentiation of feldspar types based on staining was not entirely successful due to the heavy limonite strain on most of the samples; most of the differentiation, therefore, was based on cleavage, twinning, relief, and inclusions. Extinction angles measured on twinned plagioclase grains range from 5° to 16° indicating the presence of oligoclase and albite and andesine or both. Many of the feldspar grains are elongate cleavage fragments with a length to width ratio of as much as 5:1. Some of the feldspar grains show

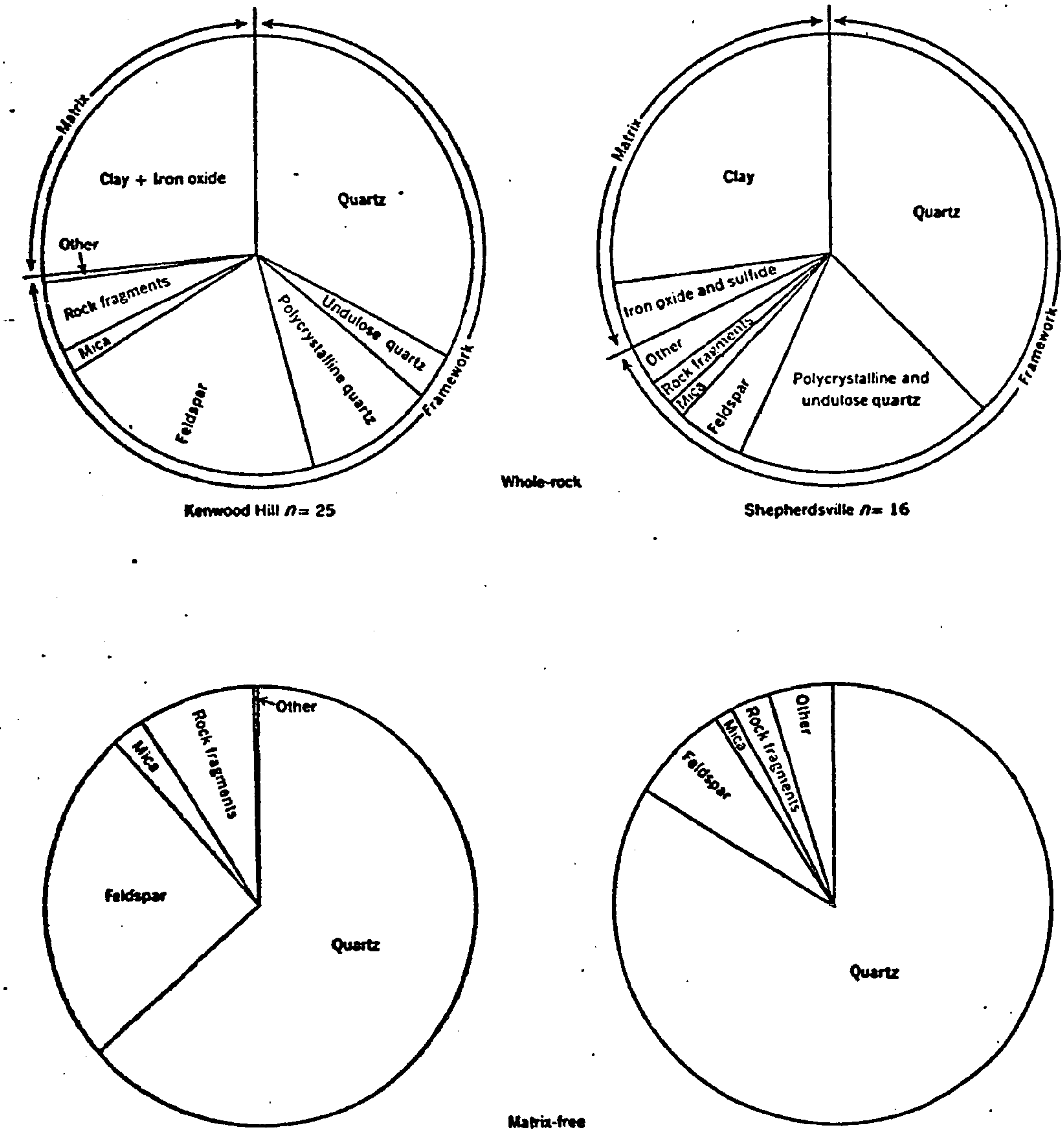


Figure 17. Pie diagrams of modal composition of Kenwood Siltstone Member of the Borden Formation, from Table 1.

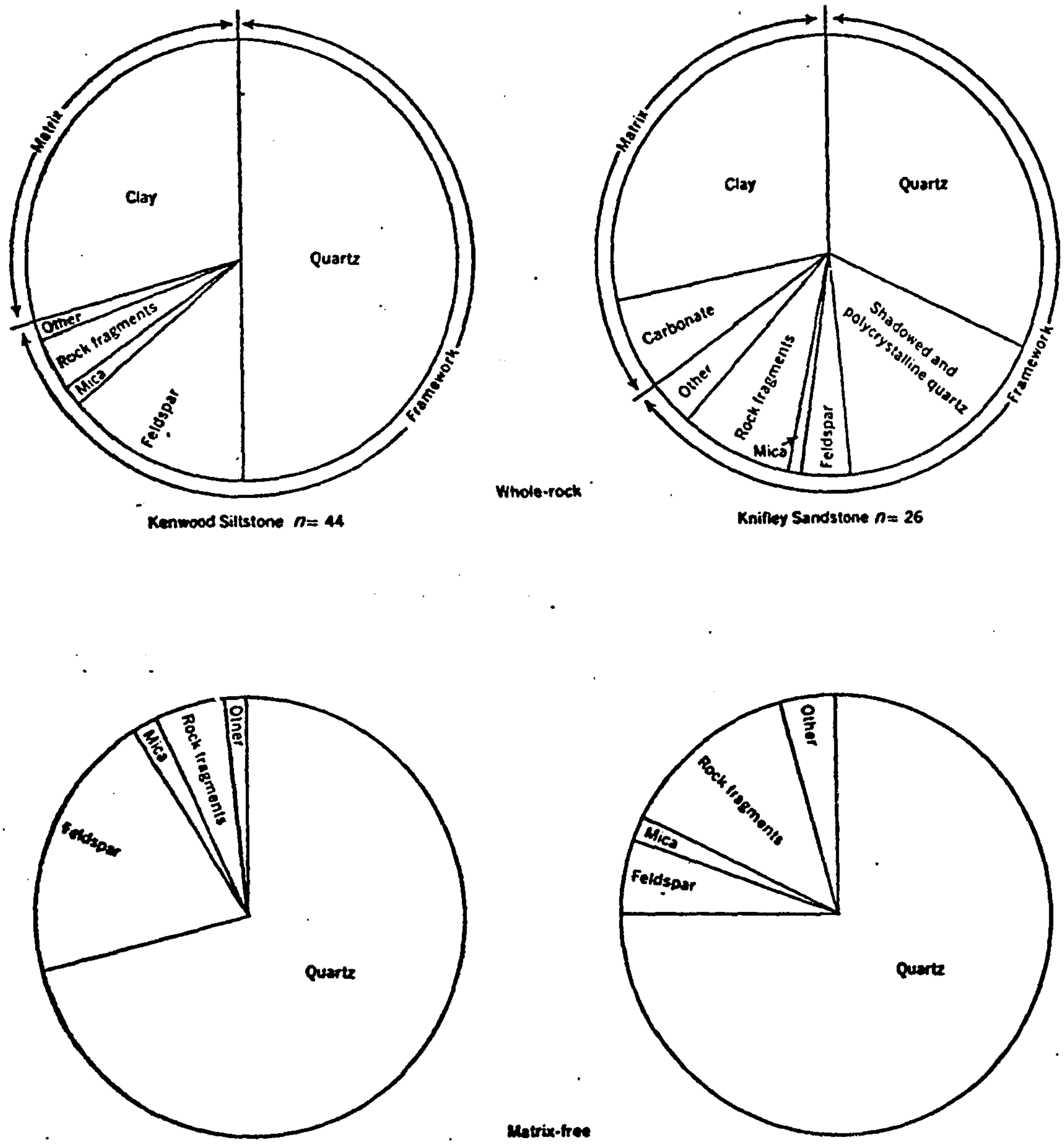


Figure 18. Pie diagrams of modal composition of Kenwood Siltstone Member of Borden Formation compared with those of Knifley Sandstone Member of Fort Payne Formation.

overgrowths and solution embayment, and many show incipient sericitization (pl. 2).

Rock fragments are the third most abundant framework constituent, ranging from 6 to 10 percent. Identified fragments include mudstone, phyllitic quartzite, and chert, although some of the quartz and chert classed as rock fragments may be secondary.

Mica is conspicuous in the Kenwood. The larger flakes range in abundance from a trace to nearly 3 percent. Not included in these figures are the smaller sericitic flakes which are considered as a part of the matrix. Of the large flakes, muscovite makes up all but about one-sixth and chlorite most of the remainder. Four mica varieties based on color (pink, colorless, brown, and green) were observed in some residue from textural analysis. In thin section, most of the mica flakes are sub-parallel to the bedding laminae; some of the flakes are bent by post-depositional compaction. Because mica is not considered in any of the schemes generally used in the genetic classification of sedimentary rocks, it is not included in the calculations of the framework constituents in this report.

Other grains found in trace amounts also were excluded in calculations of the framework constituents. These are glauconite and the heavy minerals: zircon, tourmaline, rutile, and hornblende. The glauconite appears to be pelletal aggregates of possible faecal origin. Zircon is well rounded. Tourmaline grains are light blue green and somewhat rounded at the ends.

Bulk X-ray mineralogy

Qualitative X-ray data were gathered by irradiating the polished slabs from which thin sections were obtained (Hughes, and others, 1960). Because most of the rock is in the medium-to-coarse silt range, sufficient grains were irradiated to make qualitative and, hopefulle, semiquantitative comparisons among the samples. Schultz (1964) found fair success in relating mineral composition semiquantitatively to X-ray diffraction patterns of bulk powdered samples of the Pierre Shale. Harrison and Grimes (1970) used a similar technique in making semiquantitative estimates of the mineral composition of Belt rocks. The mineral suites found in the rocks are similar to those of the Kenwood (fig. 17).

Harrison and Grimes (1970) measured peak heights and recalculated the results on the basis of 100 percent, using intensity factors modified from Schultz (1964). In investigating the Kenwood, this procedure was followed using the intensity factors listed in table 2. A sample calculation is shown on figure 19. A comparison of these results with the mineralogy as determined from thin section study (table 1) shows a fair agreement between the two methods for unweathered samples.

A major problem in thin section analysis of siltstone is the accurate identification of feldspar. Shaw and Weaver (1965, p. 210), suggest that feldspar is often completely overlooked in such studies. In an effort to evaluate my particular efforts at over-

TABLE 2

FACTORS FOR SEMIQUANTITATIVE MINERALOGY OF THE KENWOOD SILTSTONE FROM X-RAY DIFFRACTION

Minerals	Peak Position in degrees 2θ (CuKα radiation)	d-spacing (Å)	Intensity Factor
Quartz (SiO_2)	26.06	3.35	4
Plagioclase (Oligoclase)	28.0	3.20	3
K-feldspar	27.05	3.25	3
Calcite	29.4	3.05	2
Dolomite	31.0	2.9	2
Siderite	31.7-31.9	2.8	1.2
Pyrite	33.1	2.7	0.5
Clay minerals	19.8	4.52	0.2

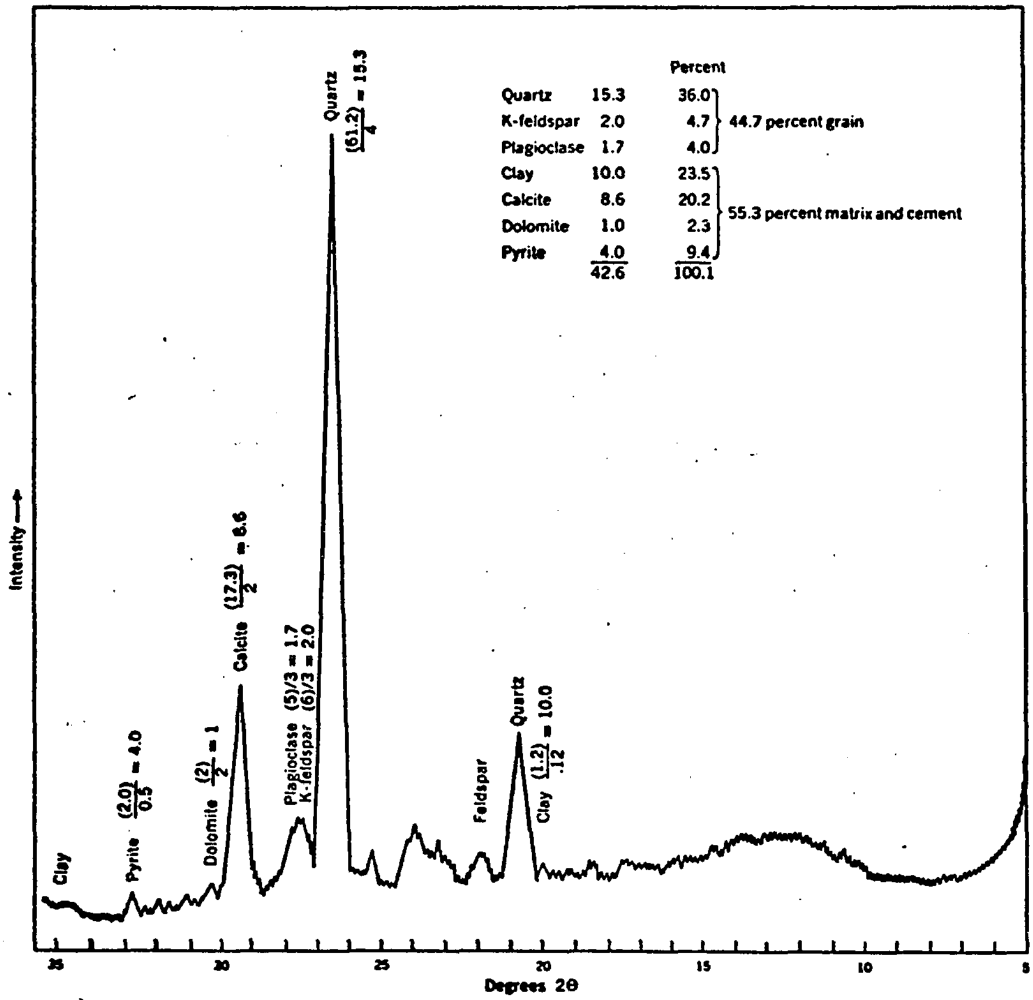


Figure 19. X-ray diffractometer trace of typical sample of Kenwood siltstone. The CuKα radiation was generated by a General Electric XRD-5 X-ray diffractometer at 40 kilovolts (kv) and 16 milliamperes (ma) using a nickel filter. The specimen was irradiated through a 3° slit with the goniometer rotating at 2° 2θ per minute (sample BR-1-1).

coming this difficulty, X-ray techniques have been used. Polished slabs were scanned over the specific 2θ range on the goniometer to include the quartz peak at 26.6° and the feldspar peaks at 27.5° and 28°. The results are compared with the modal percent feldspar relative to the total abundance of quartz + feldspar (table 3 and fig. 20). Additional X-ray traces were obtained for prepared quartz-feldspar mixtures. The minerals were ground and seived through 200 mesh screens. The powders were mixed with acetone and were mounted on glass slides. Duplicate runs irradiated different parts of the slide. These data are also included in table 3 and in figure 20.

The results indicate that feldspar may not be as abundant in most samples as was indicated by thin-section analysis. The results further suggest that the correction factors used for the quartz peak intensity on X-ray traces is probably too low in the samples that lack carbonate. By constructing a correction field from the standards, corrected values are extrapolated from peak height calculations. These indicate that the average feldspar content of the Kenwood probably is between 15 and 23 percent of the total. An assumption is made that most of the rock fragments are chert or are quartzose, thus the ratio $\frac{F}{Q+F}$ x 100 should give the percent composition of feldspar on the quartz-feldspar-rock fragment ternary classification.

The conclusion is made that the X-ray procedure, without modification for the samples or the X-ray machine used fails to fall within the 10 percent limit of accuracy claimed by Harrison and

TABLE 3A.

CALCULATIONS OF PERCENT FELDSPAR FROM X-RAY DIFFRACTION COMPARED WITH MODAL PERCENT FELDSPAR

X-ray diffraction							Modal Analysis			
Sample Number	I_Q	I_F	$\frac{I_Q}{4}$	$\frac{I_F}{3}$	$\frac{I_Q}{4} + \frac{I_F}{3}$	$\frac{I_F}{\frac{I_Q}{4} + \frac{I_F}{3}} \times 100$	Quartz + Rock Frag. + Chert (M_Q)	Feldspar (M_F)	$M_Q + M_F$	$\frac{M_F}{M_Q + M_F} \times 100$
LW-1-1	60	4	15.0	1.3	16.3	8.0	55.7	10.3	66.0	15.6
-1	76	6	19.0	2.0	21.0	9.5	55.7	10.3	66.0	15.6
-2	90	7.7	22.5	2.6	25.1	10.3	64.7	14.3	79.0	18.1
-3	68	11	17.0	2.7	19.7	13.7	57.6	14.0	71.6	19.5
-4	66	6	16.5	2.0	18.5	10.8	56.6	20.7	77.3	26.8
-5	74	7	18.5	2.3	20.8	11.1	60.7	17.3	78.0	22.2
-6	47	9	11.75	3.0	14.75	20.4	51.7	10.6	62.3	17.0
Average feldspar in bed 1						12.0				19.3
LW-1-20F	27.8	5.8	6.95	1.17	8.12	14.4	40.7	14.3	55.0	26.0
-20S	68.0	8.0	17.0	2.67	19.67	13.6	40.7	14.3	55.0	26.0
-21	37.5	3.4	9.4	1.1	10.5	10.5	43.0	28.7	71.7	40.0
-23	31.2	4.5	7.8	1.5	9.3	16.1	40.0	7.3	47.3	15.4
Average feldspar in bed 2						13.9				26.9
LW-1-30	80.0	9.0	20.0	3.0	23.0	13.0	56.0	23.7	79.7	29.1
-30	47.7	4.0	11.9	1.3	13.2	7.8	56.0	23.7	79.7	29.1
-31F	37.0	4.6	9.25	1.53	10.8	14.1	60.7	16.3	77.0	21.2
-31	43	4.4	10.75	1.47	12.2	12.2	60.7	16.3	77.0	21.2
-31	66	9.2	16.5	3.07	19.6	15.7	60.7	16.3	77.0	21.2
-33	47.2	3.4	11.8	1.13	12.9	8.7	49.7	25.8	75.5	34.2
-34	50.8	5.0	12.7	1.67	14.37	11.6	52.7	14.3	67.0	21.3
-35	49.0	6.5	12.25	2.13	14.38	14.8	48.1	25.5	73.6	34.7
-36	45.8	4.8	11.45	1.60	13.05	12.25	49.6	21.0	70.6	29.7
Average feldspar in bed 3						12.24				26.8
LW-1-40	75.0	8.0	18.75	2.67	21.42	12.5	49.7	22.1	71.8	30.8
-42	42.9	4.0	10.72	1.33	12.05	11.0	64.0	20.0	84.0	23.8
-42	108.0	13.4	27.0	4.47	31.50	14.2	64.0	20.0	84.0	23.8
-42	49.6	6.3	12.4	2.10	14.50	14.5	64.0	20.0	84.0	23.8
-43	35.2	5.0	8.8	1.67	10.47	16.0	51.3	25.7	77.0	32.5
Average feldspar in bed 4						15.0				26.8
LW-1-50	61.0	6.5	15.25	2.70	17.95	15.0	59.0	27.3	86.3	32.0
-50	42.7	3.7	10.67	1.23	11.90	10.3	59.0	27.3	86.3	32.0
-52	48.4	3.3	12.10	1.10	13.20	8.3	50.4	23.3	73.7	31.7
Average feldspar in bed 5						11.2				31.9
LW-1-60	48.0	7.0	12.0	2.33	14.33	16.3	46.0	23.7	69.7	33.0
LW-1-70	52.0	2.0	13.0	0.67	13.67	6.7	49.5	27.5	77.0	35.8
BR-1-1	61.0	11.0	15.25	3.70	18.95	19.5	35.3	14.0	49.3	28.4

TABLE 3B

CALCULATIONS OF PERCENT FELDSPAR FROM X-RAY DIFFRACTION OF PREPARED MIXTURES

Number	CPS	I_Q	I_F	$\frac{I_Q}{4}$	$\frac{I_F}{3}$	$\frac{I_Q}{4} + \frac{I_F}{3}$	$\frac{I_F}{\frac{I_Q}{4} + \frac{I_F}{3}} \times 100$	Modal Percent Feldspar
Quartz	2000	63						0
Feldspar	2000	76						100
Calcite	2000	43						0
F / Q								
.07/.65	2000	68.0	4.3	17.0	1.43	18.43	7.8	9.7
.07/.65	2000	82.4	3.8	20.6	1.27	21.87	5.85	9.7
.07/.65	5000	44.8	2.6	11.2	0.87	12.07	7.2	9.7
Average calculated feldspar							6.95	
.24/1.08	2000	48.5	7.3	12.1	2.43	14.53	16.7	18.2
.24/1.08	5000	65.7	8.0	16.4	2.67	19.07	14.0	18.2
.24/1.08	5000	34.0	3.1	8.5	1.03	9.53	10.8	18.2
Average calculated feldspar							13.8	
.12 /.42	2000	60.0	7.5	15.0	2.5	17.5	14.2	22.2
50 / 50	2000	50.5	10.1	12.6	3.37	15.97	21.1	50
50 / 50	2000	38.0	14.0	9.5	4.67	14.17	33.0	50
50 / 50	5000	28.7	6.0	7.17	2.0	9.17	21.8	50
50 / 50	5000	24.6	8.5	6.15	2.83	8.98	31.5	50
Average calculated feldspar							27.1	

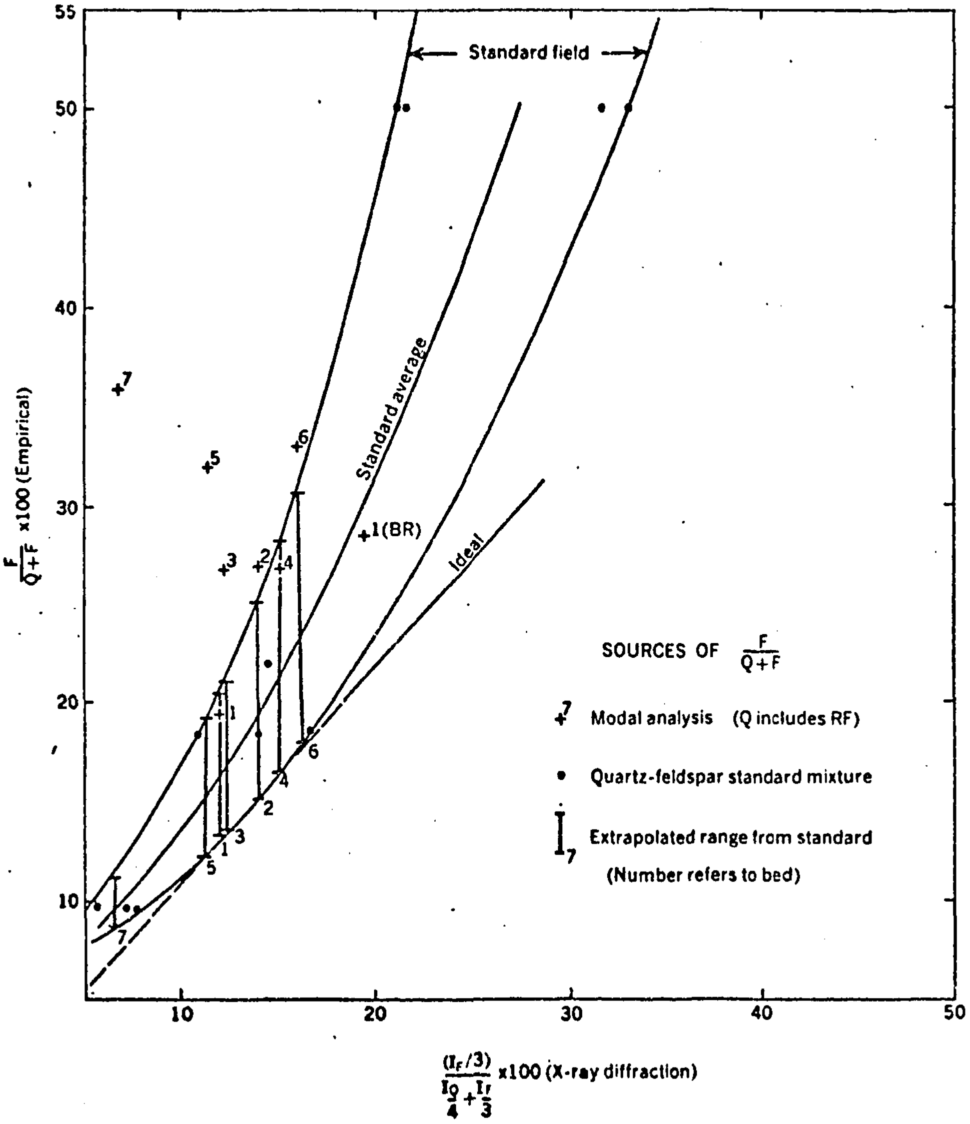


Figure 20. Feldspar content of Kenwood siltstone: comparison between X-ray diffraction and thin-section analysis.

Grimes (1970) or by Schultz (1964). This may be due in part to the fluctuation in the X-ray equipment or to omission of matrix in material from the standards. The slab method, however, is deemed appropriate for qualitative determinations of the non-clay minerals, and furnishes a basis for semiquantitative evaluation of the feldspar content of fine-grained rocks.

Siltstone classification

The classification of siltstone has long been a problem. This problem has been ignored, or, when faced, has been solved by the use of existing classifications designed for sandstone. Such classifications may be satisfactory as long as one recognizes that the genetic implications for sandstone under a given system of classification do not carry through to siltstone classified according to the same system. This becomes apparent, particularly in the sandstone classification of Folk (1954) in which polycrystalline quartz is included with the rock fragment + chert pole on the feldspar - quartz - rock-fragment triangular diagram. The quartz grains of silt size are so small that, although they may be identified as plain quartz, they actually may be individual fragments of a grain that originally was larger and polycrystalline (Gilbert, 1954, p. 296).

On the other hand, the inclusion of polycrystalline quartz grains with the rock-fragment + chert pole may be appropriate when dealing with siltstone because of the gradation in size between crystallites of polycrystalline quartz and crystallites of chert. This gradation is accentuated when using a power of magnification an order of magnitude higher than is used in sandstone grain identification. Difficulty in identification of quartz types in silt-size grains is compounded by the possibility of unrecognized superposition of grains that would give the erroneous impression of polycrystallinity.

The significance of a genetic classification system can be measured mainly through use. One of the prime measures should be the degree to which samples of common origin fall into a natural group that is distinguishable from groups of samples of different origin. To test two proposed siltstone classifications from this standpoint, the compositional data from the Kenwood siltstone are plotted on two separate triangles. One of the triangles follows the classification essentially as used by Folk in 1954. The other is a modification of a later proposal (Folk, 1968, p. 124) in which chert is the only quartz variety included with rock fragments.

Under Folk's earlier proposal eight of the beds are classed as lithic arkose, one is an arkose, one is a feldspathic sublitharenite, three are feldspathic litharenites and five are litharenites (fig. 21a). The same samples are plotted on a second triangular diagram according to the modification of the later proposal. In this plot nearly all the samples are included within the subarkose to arkose fields (fig. 21b). Because the grouping is substantiated by apparent uniformity in mineralogy exemplified in X-ray

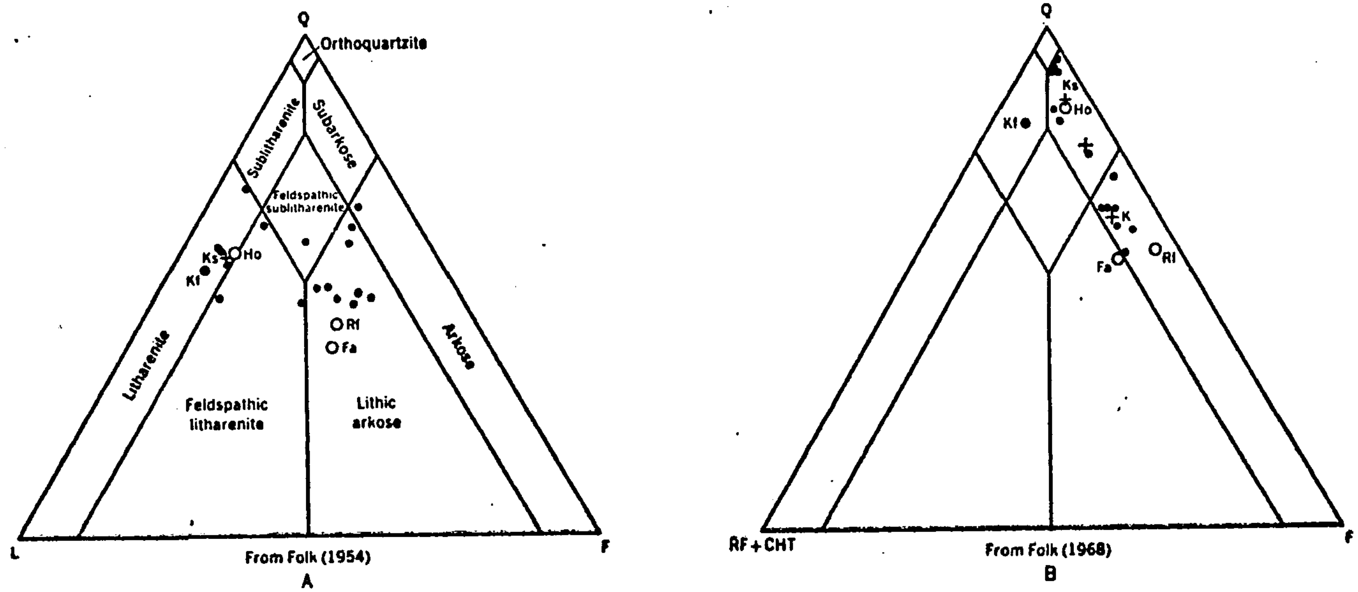


Figure 21. Composition of siltstone of Kenwood compared with that from Holtsclaw (Ho), Farmers (Fa), and Wildie (Rf) Members of the Borden Formation, and the Knifley Sandstone Member (Kf) of the Fort Payne Formation. A. Polycrystalline quartz plotted with labiles (L); B. Polycrystalline quartz included with quartz (Q). += Average Kenwood composition; Ks = south area; K = Kenwood Hill.

diffraction traces, the later classification (Folk, 1968) is recommended for use with the siltstones of the Borden. According to the recommendation of Picard (1971, p. 187), the full designation should include the matrix mineralogy; thus, the rock on the basis of laboratory study should be: clayey siltstone, illite-subarkose to -arkose.

Clay mineralogy

The clay fraction in the interbeds was examined by X-ray diffraction following suggestions of Warshaw and Roy (1961). The fraction smaller than 2 microns was air dried on a glass slide and analyzed on a goniometer rotating at 2° 2θ per minute using a 1° slit, through which CuK_{α} radiation was generated at 40 kv and 16 ma. Additional runs were made after glycolation, heating at 375° C, and heating at 575° C. The typical radiograph trace for 5 interbeds (fig. 22) shows that the main component is illite. Strong peaks at 14Å and 7Å indicates a kaolinite + chlorite. The disappearance of both peaks on heating to 575° C may indicate a septachlorite. Because chlorite is visible petrographically, the latter is believed the more likely of the two choices. Similar traces have been observed from the API standard, Beavers Bend Illite.

The approximate composition of the clay fraction of the interbedded shale of the Kenwood is 87 percent illite, 10 percent kaolinite, and 3 percent chlorite, using the technique proposed by

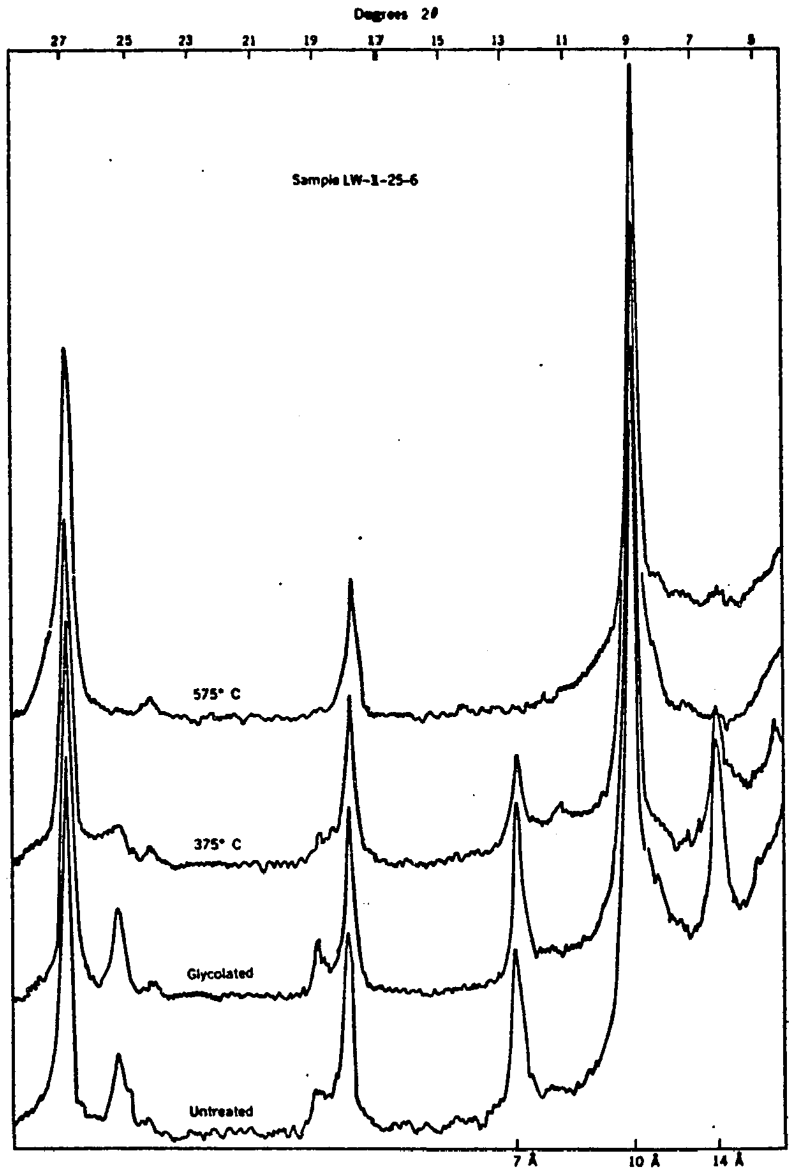


Figure 22. Typical X-ray diffraction patterns for the clay fraction of the shale interbeds of the Kenwood.

Schultz (1964) for semiquantitative clay mineral estimation. The kaolinite and chlorite combined to comply with petrographic data give the composition illite (87 percent) and septachlorite (13 percent).

Maturity

Indices of maturity that depend on composition are generally related to relative abundance of quartz, feldspar, and rock fragments. Presence and type of clay minerals are regarded by some as being significant, but their abundance may reflect mainly the current regime under which they were deposited, or the post-depositional weathering and diagenesis of the rock in which they are found.

The siltstone of the Kenwood is considered a submature subarkose siltstone that originated from a tectonically active granitic terrane. This conclusion is based on the high proportion of potassium feldspar as compared to plagioclase feldspar, the mixing of both fresh and weathered feldspar grains, and the appearance of calcite cement rather than clay in the fresher samples of siltstone.

Texture

Textural parameters have always been the basis of the primary classification schemes of clastic sedimentary rocks. According to the scheme proposed by Folk (1954), the lithologies represented by the Kenwood are medium grained siltstone and silt- to mud shale (fig. 23).

The 20-year search for statistical measures of texture that might afford bases for distinguishing sediments of different modern environments is well known (Inman, 1952; Folk and Ward, 1957; Passega, 1957; Friedman, 1967; Folk, 1968; Moiola and Weiser, 1968). In order to afford comparison with these earlier studies, descriptive statistical measures of texture were determined for each of the 47 siltstone and six shale samples of the Kenwood, using methods outlined by Folk and Ward (1957). These measures are based on values of the 5, 16, 25, 50, 75, 84 and 95th percentiles (table 4), determined from the cumulative frequency curve of the sample, and plotted in phi values on arithmetic probability paper.

Mechanical analysis of disaggregated samples was carried out by sieving and by pipette analysis of the silt-clay fraction. The following statistical measures were determined: central tendency, the dispersion, skewness, and kurtosis (table 5).

A comparison of the measures of sorting (dispersion), skewness, and kurtosis is facilitated by using the limits recommended by Folk (1968, p. 46-48). (See table 6).

Siltstone

Siltstone of the Kenwood has an average mean grain size (M_z) of 5.36Ø (0.024 mm), which is medium-grained silt on the Wentworth scale. Mean grain size ranges from 4.37Ø to 6.17Ø (0.048 - 0.014 mm).

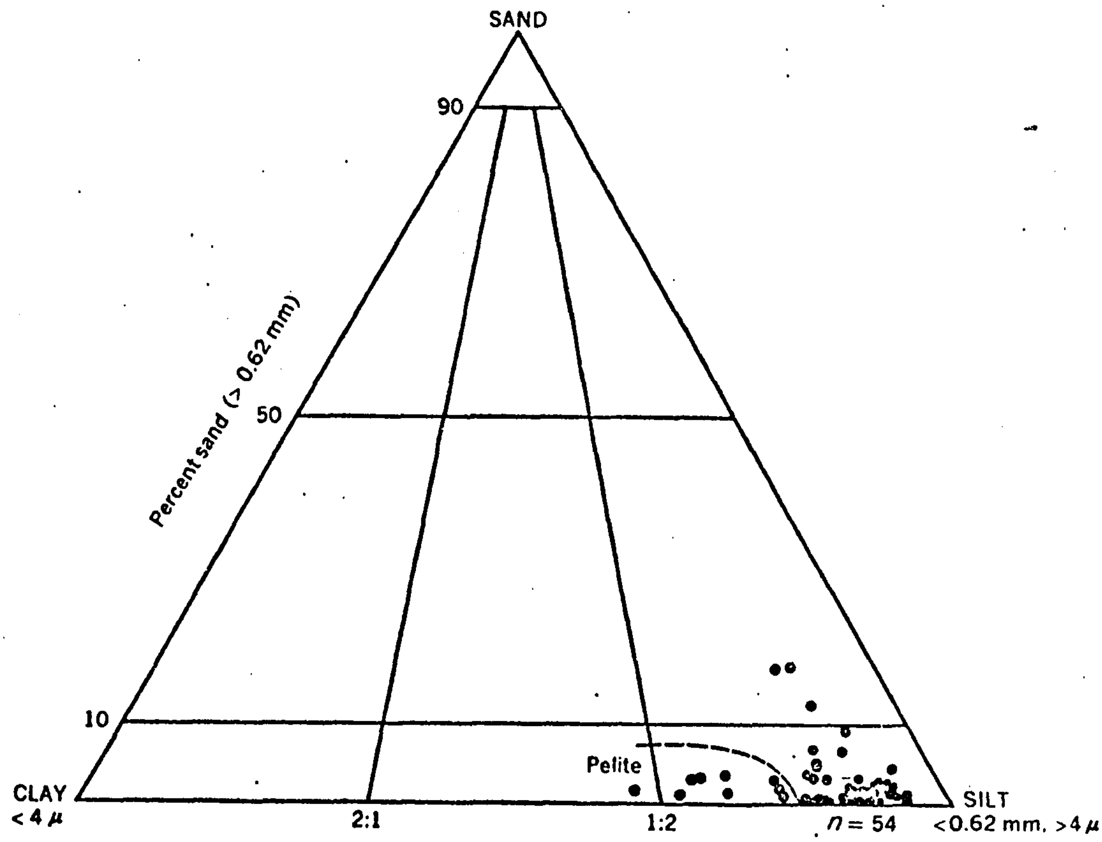


Figure 23. Silt-sand-clay triangular plot of textural analyses of the Kenwood Siltstone Member of the Borden Formation. (After Folk, 1968, p. 28.)

TABLE 4

STATISTICAL PARAMETERS FOR TEXTURAL ANALYSIS OF THE KENWOOD

Part I. Siltstone

Sample No.	Grainsize in phi units at designated percentile on cumulative curves											
	C 1%	5%	16%	25%	M_d 50%	75%	84%	95%	$M_z(\phi)$	Sk_I	$\sigma_{I(\phi)}$	K_G
LW-1T	3.85	4.20	4.50	4.65	4.95	5.25	5.55	10.30	5.00	+.45	1.20	4.18
LW-1B	3.75	4.05	4.35	4.50	4.80	5.10	5.20	10.00	4.78	+.34	1.11	4.07
LW-2T	3.70	4.10	4.40	4.60	4.95	5.95	7.40	10.20	5.58	+.68	1.68	1.86
LW-2B	3.40	3.80	4.20	4.40	4.75	5.15	5.40	10.20	4.78	+.39	1.27	3.50
SH-1T	3.40	3.95	4.35	4.90	5.20	6.00	7.60	10.35	5.72	+.46	1.78	2.39
SH-1M	3.10	3.70	4.20	4.75	5.10	5.65	7.00	10.22	5.43	+.47	1.69	2.95
SH-1B	2.85	3.50	4.10	4.65	4.95	5.80	7.00	9.45	5.35	+.55	1.62	2.12
SH-2T	3.45	4.00	4.45	4.75	5.30	5.80	7.25	10.62	5.67	+.57	1.70	2.58
SH-2B	3.30	3.90	4.35	4.65	5.20	5.75	7.25	10.35	5.60	+.51	1.70	2.41
SH-3T	4.10	4.35	4.60	4.70	4.95	5.20	5.35	10.25	4.97	+.43	1.08	4.83
SH-3B	3.85	4.15	4.45	4.60	4.90	5.20	5.35	10.25	4.90	+.38	1.14	4.17
SH-4	3.60	3.95	4.20	4.60	4.75	5.10	5.25	8.00	4.73	+.28	0.88	3.34
SH-5	3.75	4.05	4.35	4.65	4.85	5.15	5.90	8.55	4.37	+.50	1.07	3.72
SH-6	3.90	4.20	4.45	4.80	4.95	5.25	5.40	9.20	4.93	+.32	1.00	4.54
SH-16T	2.70	3.20	3.85	4.20	5.05	5.85	6.80	10.30	5.23	+.33	1.81	4.46
SH-16B	2.15	2.95	3.75	4.10	4.90	5.70	6.10	10.20	4.92	+.24	1.89	4.96
LW-1-70	4.11	4.32	4.52	4.62	4.83	5.01	7.30	10.57	5.55	+0.807	1.641	5.08
LW-1-62	4.06	4.37	4.67	4.81	5.13	7.00	8.71	10.65	6.17	+0.765	1.960	1.17
LW-1-61	3.96	4.23	4.50	4.62	4.89	6.24	7.57	10.38	5.65	+0.771	1.697	1.56
LW-1-60	3.84	4.19	4.52	4.68	5.07	7.11	8.48	10.47	6.02	+0.726	1.943	1.03
LW-1-52	4.02	4.28	4.50	4.62	4.87	5.55	7.06	10.00	5.48	+0.753	1.506	2.53
LW-1-51	3.97	4.22	4.45	4.58	4.82	5.40	6.80	9.60	5.36	+0.732	1.407	2.69
LW-1-50	3.90	4.12	4.38	4.52	4.78	5.50	6.73	9.50	5.30	+0.707	1.403	2.25
LW-1-43	4.10	4.33	4.57	4.68	4.90	5.88	6.90	10.18	5.49	+0.760	1.468	2.01
LW-1-42	3.88	4.18	4.44	4.58	4.87	5.93	7.46	10.32	5.58	+0.731	1.711	1.89
LW-1-41	3.98	4.19	4.43	4.58	4.82	5.30	6.95	10.10	5.40	+0.739	1.525	3.38
LW-1-40	3.87	4.15	4.40	4.52	4.78	5.03	6.02	9.56	5.07	+0.650	1.225	4.36
LW-1-36	4.12	4.32	4.53	4.62	4.83	5.08	6.82	9.96	5.39	+0.777	1.430	5.03
LW-1-35	4.15	4.36	4.57	4.68	4.88	5.43	7.10	10.16	5.52	+0.788	1.512	3.17
LW-1-34	4.07	4.30	4.51	4.62	4.83	5.42	7.05	10.10	5.46	+0.781	1.515	2.97
LW-1-33	4.11	4.33	4.55	4.66	4.88	5.62	7.10	10.00	5.51	+0.789	1.471	2.42
LW-1-32	4.05	4.28	4.51	4.62	4.84	5.68	7.19	10.15	5.51	+0.782	1.582	2.31
LW-1-31	4.03	4.28	4.50	4.62	4.86	5.59	6.75	10.05	5.37	+0.736	1.427	2.42
LW-1-30	4.03	4.27	4.51	4.62	4.86	5.52	6.90	10.02	5.42	+0.751	1.460	2.63
LW-1-23	4.23	4.50	4.74	4.87	5.14	6.73	8.15	10.50	6.01	+0.774	1.762	1.34
LW-1-21	4.16	4.43	4.68	4.82	5.08	6.51	7.68	10.40	5.81	+0.760	1.653	1.45
LW-1-20	4.22	4.46	4.68	4.80	5.04	6.56	7.85	10.38	5.86	+0.788	1.68	1.38
LW-1-6	4.18	4.40	4.62	4.73	4.95	6.40	7.88	10.46	5.82	+0.808	1.734	1.49
LW-1-5	4.05	4.28	4.47	4.58	4.80	5.02	6.45	10.18	5.24	+0.745	1.390	5.50
LW-1-4	4.08	4.30	4.50	4.60	4.80	5.20	7.00	10.25	5.43	+0.790	1.528	4.07
LW-1-3	4.00	4.22	4.43	4.54	4.75	5.00	6.00	8.40	5.06	+0.720	1.026	3.73
LW-1-2	3.95	4.19	4.41	4.51	4.73	4.95	5.75	8.10	4.96	+0.697	0.925	3.64
LW-1-1	3.82	4.12	4.35	4.48	4.73	4.98	5.57	8.42	4.88	+0.550	0.955	3.51
Part II. Shale												
LW-1-54	3.60	4.40	5.20	5.62	6.40	8.50	10.00	10.95	7.20	+0.444	1.113	0.932
LW-1-44	4.10	4.91	5.70	6.09	6.90	9.00	10.10	11.04	7.57	+0.403	2.028	0.865
LW-1-37	3.45	4.38	5.32	5.75	6.74	8.48	9.78	10.90	7.28	+0.432	2.104	0.945
LW-1-10	3.80	4.48	5.14	5.42	6.10	8.15	9.55	10.88	6.26	+0.529	2.072	0.963
LW-1-9	3.86	4.65	5.45	5.85	6.68	8.85	10.10	11.05	7.41	+0.419	2.133	0.875
LW-1-7	3.92	4.68	5.68	6.15	7.18	9.10	10.05	11.00	7.68	+0.270	2.05	0.878

TABLE 5

STATISTICAL MEASURES OF GRAIN-SIZE PARAMETERS
(Folk, 1968, p. 45-48)

Measure		Parameter
Central tendency	1. Phi median diameter	$Md_{\phi} = \phi 50$
	2. Graphic mean	$M_z = \frac{\phi 16+\phi 50+\phi 84}{3}$
Dispersion	3. Inclusive graphic standard deviation	$\sigma_I = \frac{\phi 84-\phi 16}{4} + \frac{\phi 95-\phi 5}{6.6}$
Skewness (asymmetry)	4. Inclusive graphic skewness	$Sk_I = \frac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \frac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$
Kurtosis	5. Graphic kurtosis	$K_G = \frac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)}$

TABLE 6

LIMITS RECOMMENDED FOR STATISTICAL MEASURES
(Folk, 1968, p. 46-48)

a. Sorting

σ_I value (in phi units)	Sorting Class
Under 0.35	very well sorted
0.35-0.50	well sorted
0.50-0.71	moderately well sorted
0.71-1.0	moderately sorted
1.0-2.0	poorly sorted
2.0-4.0	very poorly sorted
over 4.0	extremely poorly sorted

b. Skewness

Sk_I value	Skewness Class
+1.0-+0.3	strongly fine-skewed
+0.3-+0.1	fine skewed
+0.1 to -0.1	near symmetrical
-0.1 to -0.3	coarse-skewed
-0.3 to -1.0	strongly coarse-skewed

c. Kurtosis

K_G value	Kurtosis Class
less than 0.67	very platykurtic
0.67-0.90	platykurtic
0.90-1.11	mesokurtic
1.11-1.50	leptokurtic
1.50-3.00	very leptokurtic
over 3.00	extremely leptokurtic

The siltstone is poorly to moderately sorted; the inclusive graphic standard deviation (σ_I) ranges from 0.88ϕ to 1.96ϕ and averages 1.28ϕ. The frequency curves are strongly fine-skewed with skewness values ranging from Sk_I= + .24 to + .81 and averaging + .62. The curves are also leptokurtic to extremely leptokurtic with kurtosis values ranging from K_G= 1.35 to 5.50 and averaging 3.46.

Shale

Grain size analysis for six shale samples from the Kenwood Hill section indicates that the shale is mud- to silt-shale. Mean grain size (M_z) ranges from 6.26ϕ to 7.68ϕ (13 to 4.9 microns) and averages 7.23ϕ (6.7 microns). The shale is poorly to very poorly sorted; inclusive graphic standard deviation (σ_I) ranges from 1.11ϕ to 2.13ϕ. The shale, like the siltstone, is strongly fine skewed; graphic skewness (Sk_I) ranges from +.27 to +.53. The frequency curves are platykurtic to mesokurtic; graphic kurtosis (K_G) ranges from 0.86 to 0.93 (table 4).

Frequency curve comparisons

Typical frequency curves of the siltstone and shale samples from the Kenwood are compared with one from the sandstone body constituting the Knifley Sandstone Member of the Fort Payne Formation (fig. 24). Clearly the two are texturally dissimilar. (See stratigraphic chart, fig. 5 and map, fig. 6). A histogram of a typical analysis of the Kenwood is shown on figure 25.

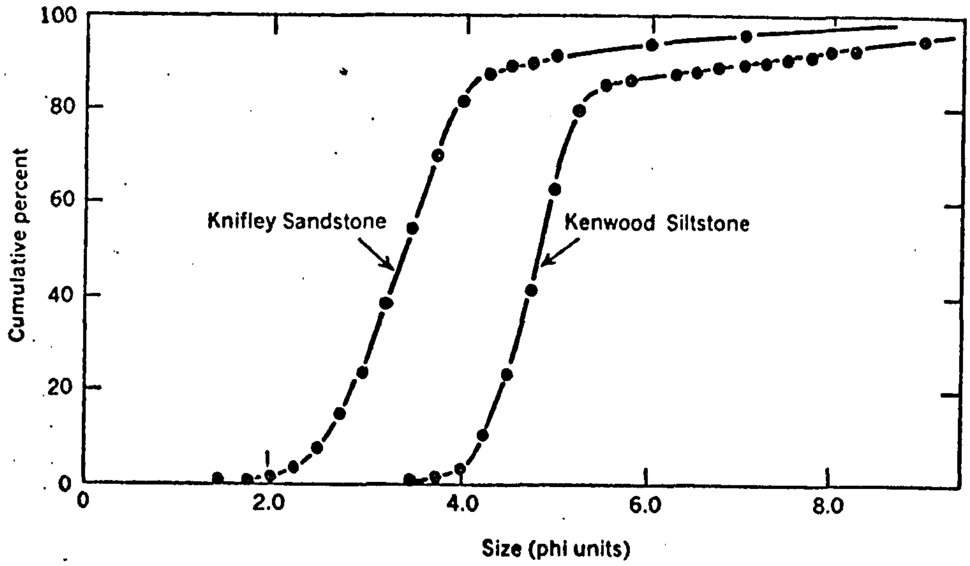


Figure 24. Comparison of granulometric analyses of the Kenwood siltstone and the Knifley Sandstone Member of the Fort Payne Formation.

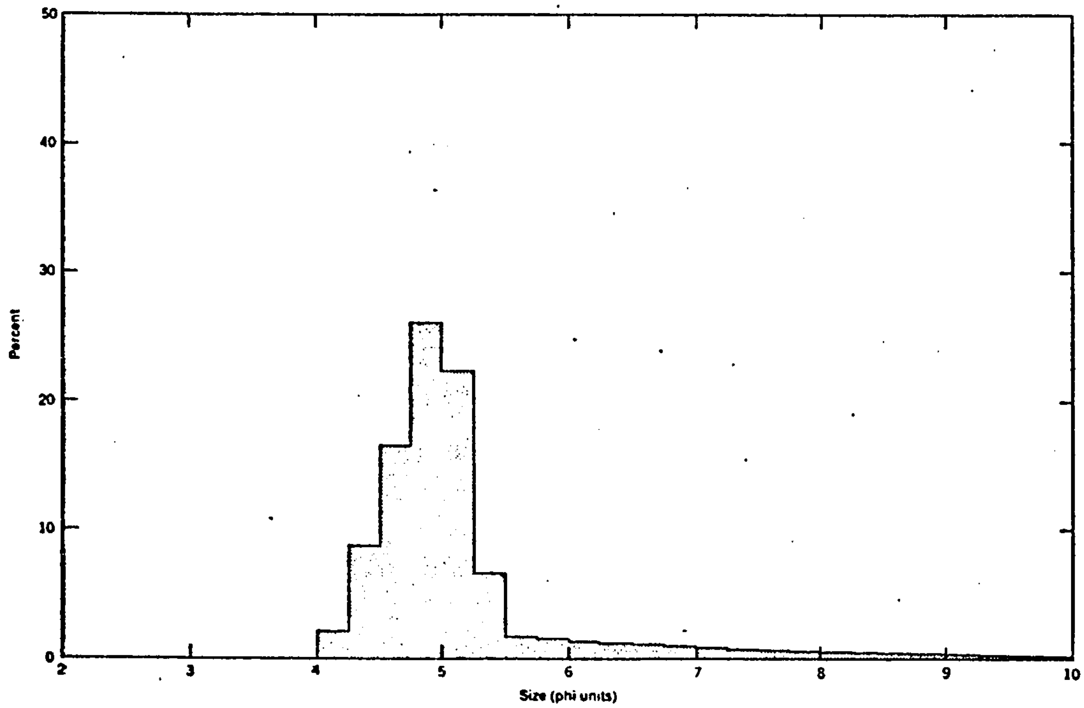


Figure 25. Histogram of grain size in a typical siltstone sample of the Kenwood Siltstone Member of the Borden Formation.

The significance of the shape of frequency curves in discriminating among sedimentary environments has received considerable attention from such workers as Krumbein (1937, 1938), Doeglas (1950), Sindowski (1958), and more recently by Visher (1969). Doeglas aptly points out the various factors that might influence the pattern of the grain-size curves: gradual change in the nature of the suspension by deposition of the coarsest and successively finer particles, fluctuations in the rate of deposition from suspension, reworking of a deposit due to an increase in the capacity of the current, and mixing of deposits due to fluctuations in the current velocity. Visher (1969) emphasizes the significance of the change in slope of the grain-size curves when cumulative phi values are plotted on probability paper, and attributes major breaks in slope to mixing of populations from suspension, saltation, and surface creep.

Several aspects of Visher's (1969) study serve to point out shortcomings in the use of the grain-size curve pattern for the interpretation of depositional environments. Visher does not include siltstone curves in his discussion, nor is mention made of possible effects of compaction of the sediment subsequent to deposition. Neither is mention made of laboratory disaggregation techniques and their possible effect on the actual size of the original sediment. For example, the original size of silt and clay pellets and clay floccules may be completely obliterated by post-depositional compaction and diagenesis. Pellets and floccules are difficult to detect in thin section and are impossible to identify from mechanical analysis, where complete dispersion of discrete particles is sought as a matter of routine (Weiler, 1970, p. 1260).

Slope breaks in the cumulative curves of grain-size analyses of the siltstone of the Kenwood are distinctly different from those of curves of shale analyses (fig. 26), yet both populations are so fine that they normally would be attributed to suspension currents. If so, the explanation by Visher that such curves represent mixing of suspended, saltated, and creep populations seems inapplicable. Perhaps they do represent a mixed population. If they do, the mixed population must have been subsequently deposited uniformly from suspension in one manner suggested by Doeglas (1950) and Weiler (1970, p. 1260). Or perhaps these characteristics merely reflect analytical techniques and dispersion on a population that was nearly uniform in grain size when deposited.

Coarsest grain

The coarsest grain was determined from an average of the 10 coarsest grains in each siltstone thin section. The results for samples from Kenwood Hill are plotted with median diameter as determined from mechanical analysis on a vertical profile of the measured section (fig. 27). This plot shows an overall fining-upward tendency in both coarsest grain and median grain-size in five of the six beds for which a comparison can be made. This tendency is slight, however, and the central part of the third bed

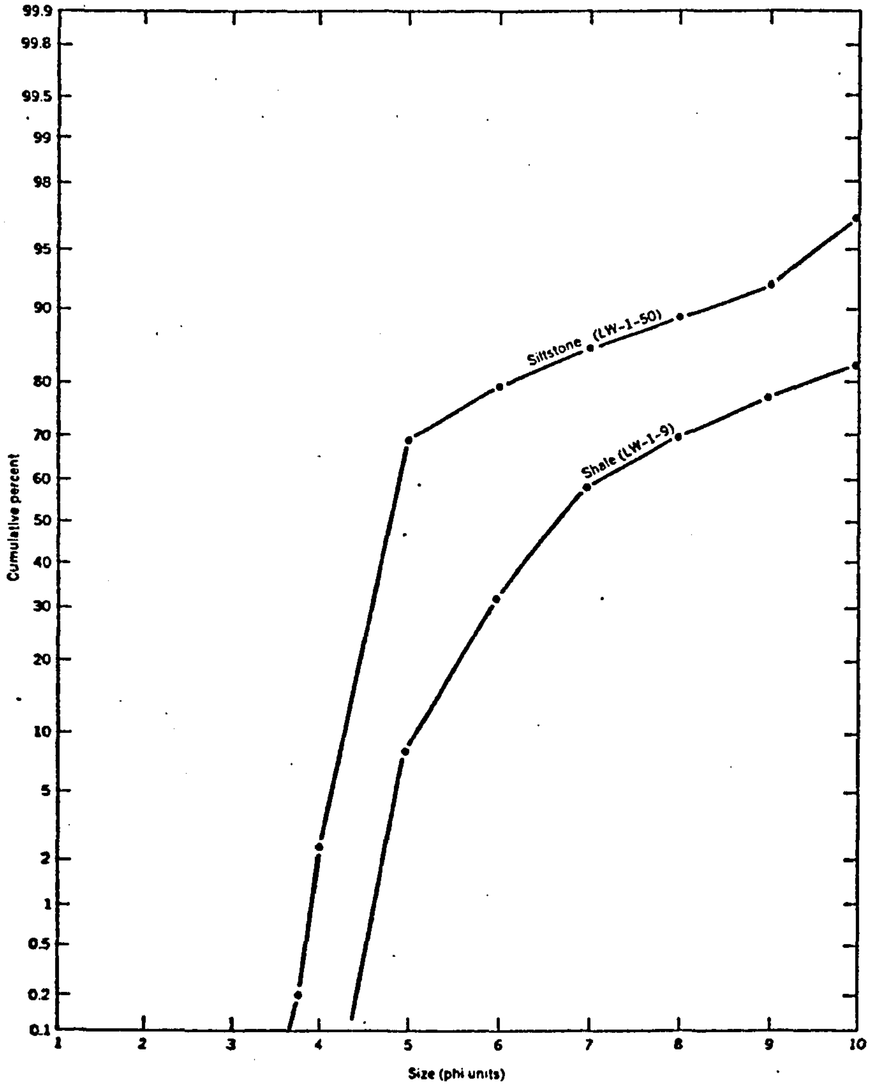


Figure 26. Cumulative curves of grain-size distribution of siltstone and shale of Kenwood compared on probability paper.

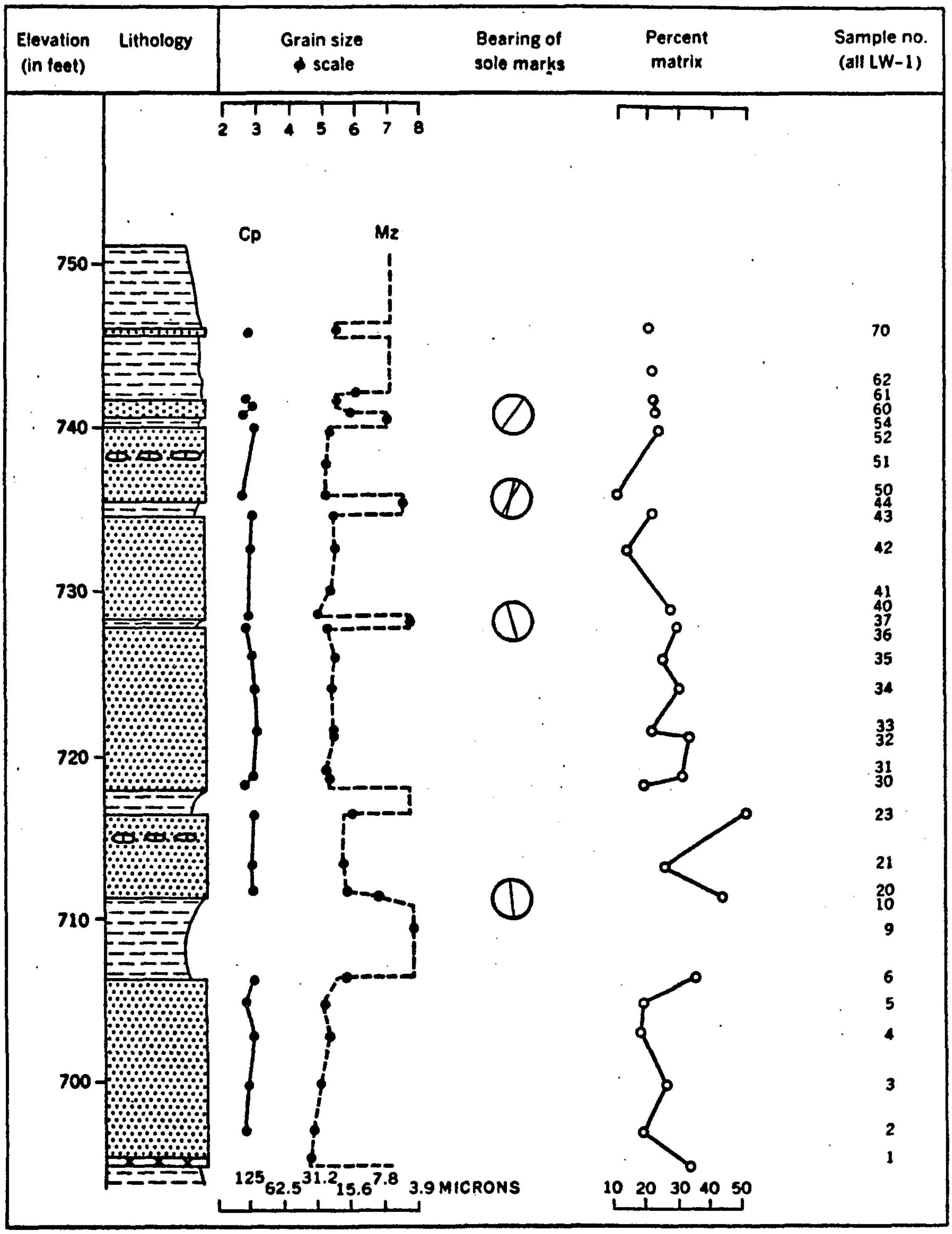


Figure 27. Columnar section of exposure of Kenwood Siltstone Member at type locality (loc. E, fig. 7), showing vertical variation in coarsest grain, determined petrographically (Cp), Graphic mean grain size (Mz), and sole mark lineation.

from the base shows the reverse trend. This fining-upward in grain size is the main manifestation of grading in the Kenwood siltstone beds. This tendency is also shown by all the other beds for which basal, middle, and top, or base and top samples were analyzed texturally. For all of these the fining upward tendency is most marked by a decrease or loss of the very fine sand fraction of the sample (fig. 28).

The basal bed of the sequence on Kenwood Hill also shows a slightly coarser grain size as a whole than do the other beds in the sequence. Comparable sequences elsewhere in the Kenwood have not been examined in sufficient textural detail to determine the extent of this phenomenon.

Textural maturity

The siltstone is texturally immature according to the maturity scheme applied to sandstone by Folk (1968, p. 108), based on the facts that the siltstone grains are subangular to angular and most samples contain more than 5 percent clay. Because angularity is common for most silt grains, however, comparison of the textural maturity of siltstones with the maturity of sandstones appears inadvisable. In this respect then, the maturity of siltstones is better indicated by composition rather than texture. Detailed roundness determinations were omitted also because of the common angularity noted for most silt-size grains.

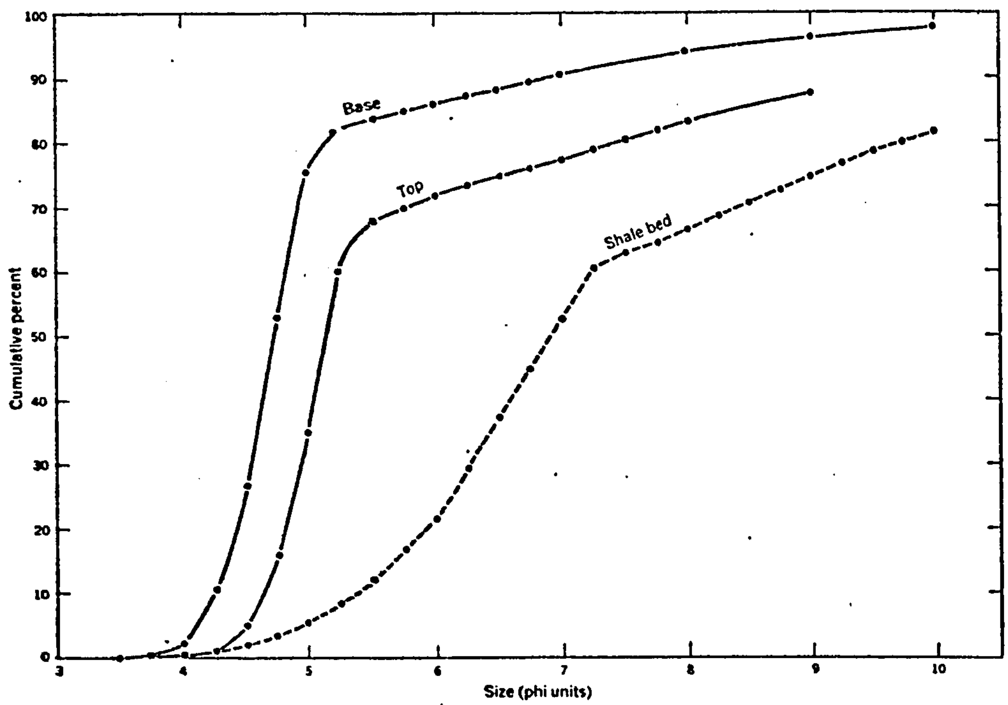


Figure 28. Cumulative grain-size curves for sample from base (LW-1-1) and top (LW-1-23) of siltstone beds, and of silt shale interbed (LW-1-44) in the Kenwood Siltstone Member.

Depositional environment indicators

Tests for parameters useful in discriminating among various possible depositional environments have been variously received. Those involving skewness seem most acceptable. Hails and Hoyt (1969) concur with Folk and Ward (1957) in concluding that skewness versus kurtosis is in some cases the most environment-sensitive measure, particularly in regard to barrier island, lagoon, and salt marsh environments. They agree with Folk in their high regard for skewness, a measure of the tail fraction of curves, as being related to the energy variations in different sedimentary environments. Negative skewness results from the winnowing away of the fines in a high energy environment; positive skewness results from the lack of persistent winnowing currents (Hails and Hoyt, 1969, p. 579).

Statistical measures of textural data for the Kenwood, however, show no significant pattern when plots are made of inclusive graphic skewness vs. graphic kurtosis (fig. 29), graphic mean vs. inclusive graphic skewness and graphic mean vs. inclusive graphic standard deviation (fig. 30).

Coarse and fine tails of textural curves are also essential to considerations by Passega in discriminating among various depositional environments. He has proposed the C-M diagram (Passega, 1957) and the grain size image plot (Passega and Byramjee, 1969). The C-M diagram compares the grain-size of the

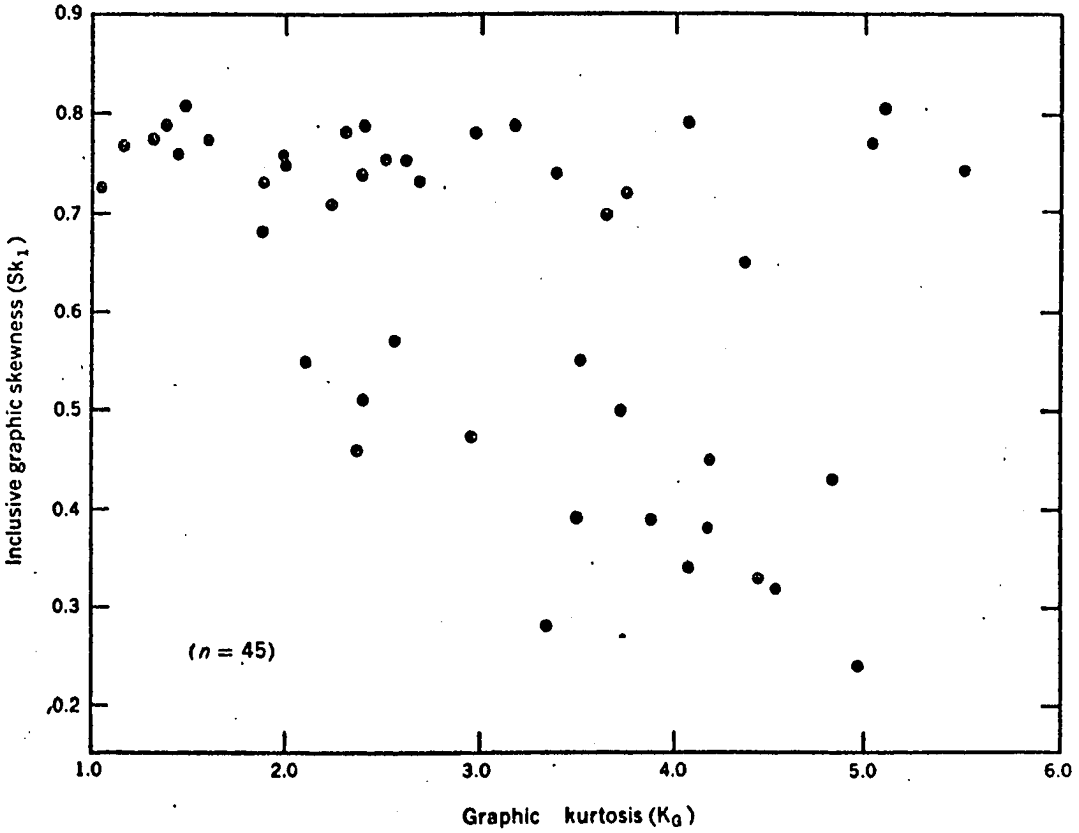
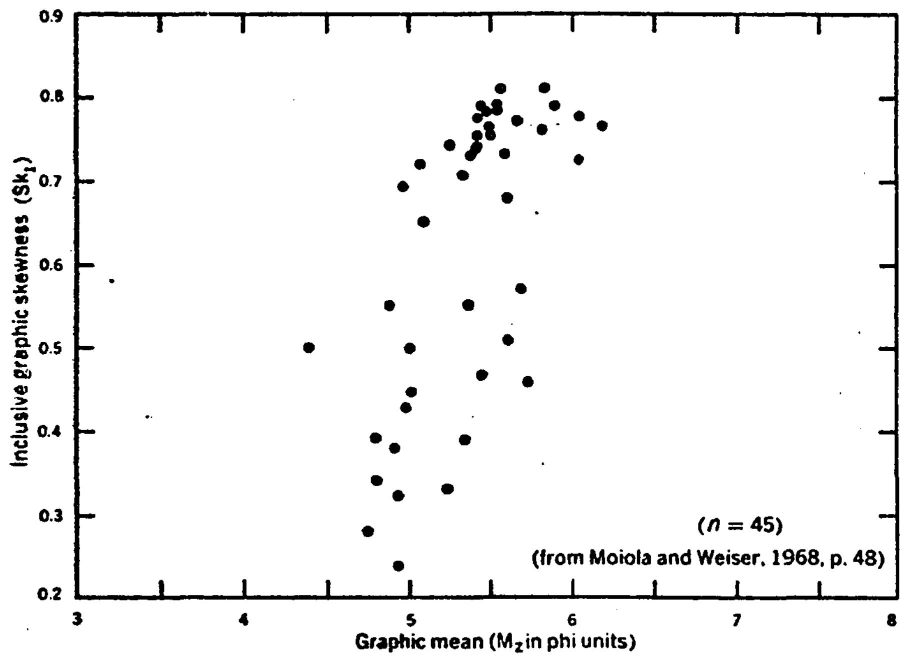


Figure 29. Comparison of textural parameters for the Kenwood siltstone: Skewness vs. Kurtosis.



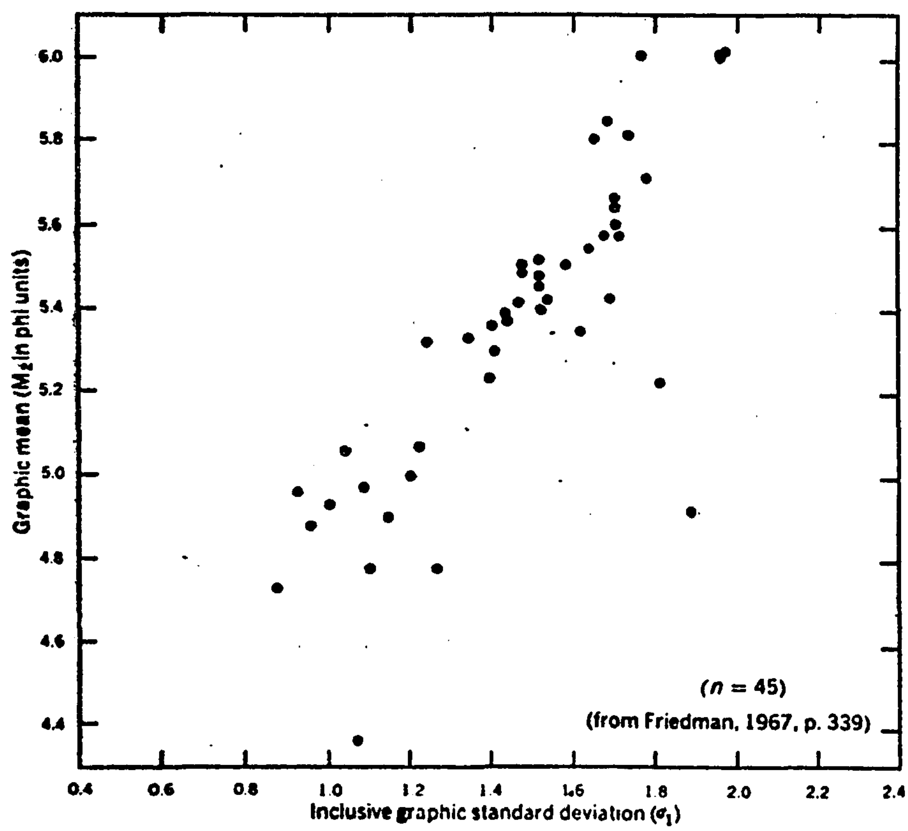


Figure 30. Comparison of textural parameters for the Kenwood siltstone: Top, Skewness vs. Mean; bottom, Mean vs. Standard deviation.

99th percentile (or first percentile on cumulative grain size curves plotted herein) with the mean. Textural data for the Kenwood plotted on the modified C-M diagram fall near the fine end of the turbidite field, and continue between that field and the field for pelagic suspension (fig. 31).

The grain size image plot (F-M, L-M, and A-M diagram, Passega and Byramjee, 1969, in which F, L, and A, respectively, are the percentages by weight in the samples of grains finer the 3Ø, 5Ø, and 8Ø) produce a series of curves similar to those considered by Passega and Byramjee (1969, p. 245) as characteristic of a uniform suspension (fig. 32).

These various plots and the positive skewness of the textural curves for the Kenwood show that both the siltstone and shale were deposited under conditions in which winnowing currents were rare or absent. Comparison with textural plots (Passega, 1957, and Passega and Byramjee, 1969) suggest that the deposits originated from pelagic suspension or turbidity currents. Little likelihood is found that the silt and shale of the Kenwood originated in a barrier island, lagoon, or salt marsh environment.

Bedding structures

Bedding structures include internal and external bedding features of sedimentary origin and features of organic origin. Features of sedimentary origin include bedding laminae, ripples, and substratal tool and current marks; features of organic origin

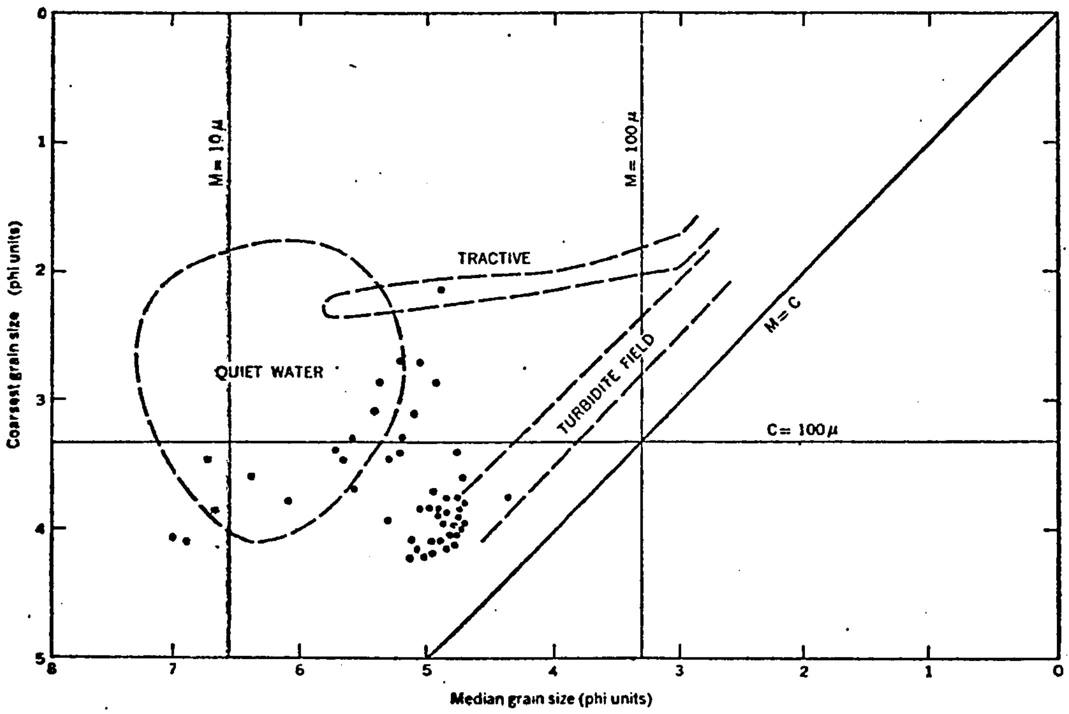


Figure 31. Grain-size image of the Kenwood on the C-M diagram (after Passega, 1957).

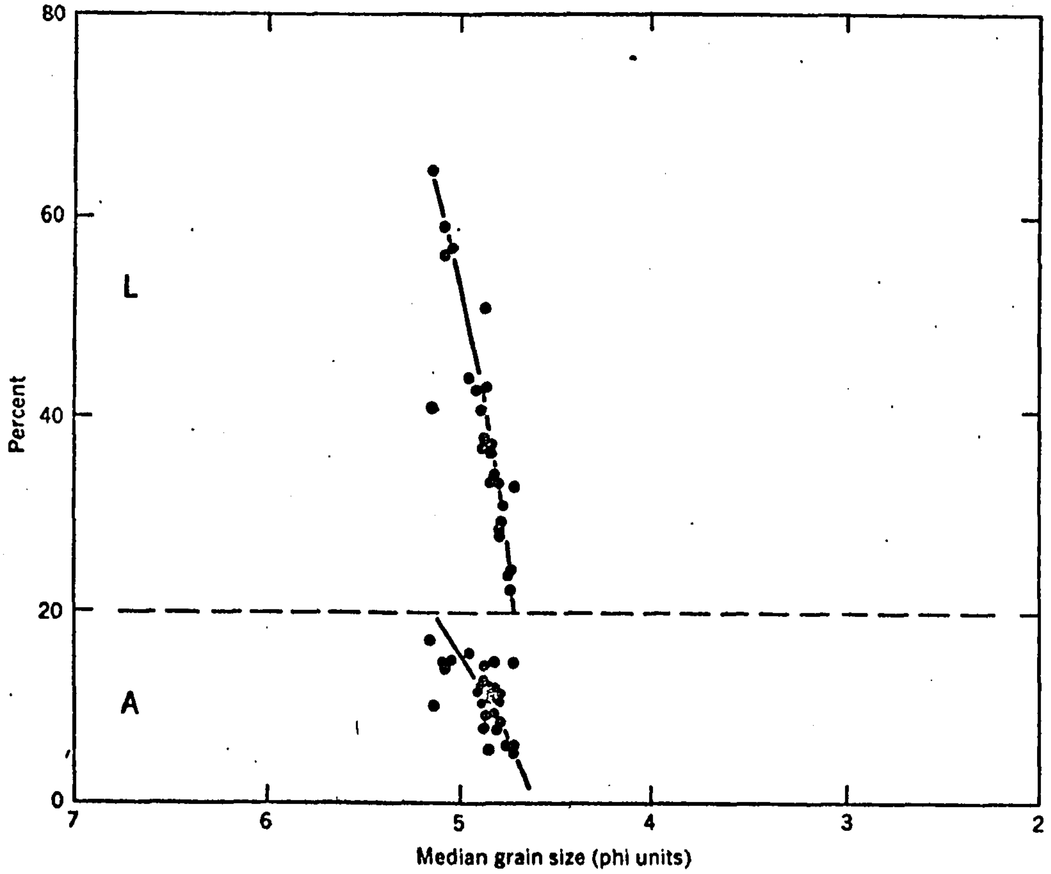


Figure 32. Grain-size image of the Kenwood on the L-M and A-M diagram (after Passega and Byramjee, 1969, fig. 4). A = percent finer than 8∅; L = percent finer than 5∅ on cumulative grain-size curves.

include burrows, tracks, and trails generally considered as Problematica, trace fossils, or ichnofossils. Sedimentary structures furnish primary evidence regarding direction and velocities of depositional currents, and trace fossils are indicators of depth of water.

Some of these features are readily seen, others are more obscure. To a casual observer, individual siltstone beds of the Kenwood may appear homogeneous, whether viewed on a weathered outcrop or on a broken surface. This apparent homogeneity is probably due to the smallness of the silt-size particles, and the inability of the eye to discriminate among variations that are masked by size, weathering products, or internal reflections from fractured grains. Internal structural features are therefore best seen on a cut slab, or in X-radiographs of a thin slab.

Internal sedimentary structures

Ubiquitous among the bedding structures in the Kenwood siltstone beds are planar horizontal bedding laminae. These laminae are subparallel to the base of the bed, and in most beds appear to make up the only internal bedding structures of depositional origin. (See X-radiograph, pl. 4). Some of this lamination can be seen in thin-section and appear to be due to microsorting of grain layers and interlayers of clayey laminae. Some of the lamination is enhanced in thin section by orientation of elongate grains and mica flakes subparallel to the base of the bed. Upon weathering, some of the beds show a tendency to part along these laminae.

Convolute laminae with associated flame structures are rare (pl. 5). Zones in which they occur are less than 0.5 feet thick and constitute less than one-third of the thickness of the bed. The convolutions approach in appearance the inverted-mushroom shape of load casts or an arrested interchange between two layered media of differing density, in which the upper layer was more dense than the lower. The origin has been attributed to refluidization during deposition of the bed (ten Haaf, 1956, p. 194).

Ripple laminations are rare; most are expressed as a single "starved" layer one ripple amplitude in height, in which the ripple amplitude is less than 0.1 foot and the wave-length is from 0.3 to 0.4 foot. Most of the beds in which ripple laminae are visible also contain convolute laminae below the rippled layer. In one exceptional bed there are three rippled layers: one below and one above a convoluted layer and a third as climbing ripples (pl. 6).

Massive bedding in which bedding laminae are lacking is extremely rare. One instance in which massive bedding can be identified clearly is in a slightly weathered exposure along the Lookout Tower Road section in Bernheim Forest (pl. 5). Here the basal part of the bed is massively bedded and overlain by horizontally laminated bedding. Grading in this massive layer cannot be demonstrated readily because of the pervasive siltsize of the grains.

A form of grading in some of the beds is shown by a lag concentrate of ostracode (?) tests, and by the inclusion of clay clasts in the basal part of some beds. In addition, the fairly widespread occurrence of iron sulfide in the basal part of the basal siltstone bed in the Kenwood sequence is attributed to possible grading.

Sideritic "ironstone" concretions are common within the siltstone beds. The concretions occur as individual spherical zones of cement, grading to coalescing zones that impart a pseudo-layering appearance to the bed. Rarely do beds contain more than one layer of such concretionary zones; commonly the zone is restricted to the middle of the bed (pl. 7). The zones are most prevalent in the beds with a thickness greater than 1 foot, and the zones appear to occupy about the same interval as does the rarely observed convolute bedding, implying a genetic relationship between the two. Upon weathering, most of these layers are altered to limonite in concentric liesegang rings that further obscure the original structure of the bedding.

The siderite is not restricted to the siltstone beds of the Kenwood, but also occurs in the shale interbeds, as was mentioned in the discussion of stratigraphy. More spectacular because of their greater contrast with the enclosing sediments are the continuous zones of siderite nodules in the New Providence Shale Member below the Kenwood. In the Lebanon Junction (Peterson, 1967) and Shepherdsville quadrangles (Kepferle, 1968a), the sideritic zones appear to be continuations of the siltstone beds of the Kenwood. The centering of a nodule on a thin siltstone bed (pl. 7) demonstrates the transition of one type of occurence to the other. From this it is concluded that the zones along which the siderite concretions are concentrated were slightly more porous than the adjacent sediment and were avenues of fluids enriched in iron which engendered the formation of the concretions.

In exceptional exposures, a zonation appears in the pelitic material immediately beneath the siltstone beds. This may be similar to zonation reported in limestone turbidite sequences and called the "pre-phase" (Meischner, 1964, p. 159). Their origin has been attributed to currents in advance of the main density current. These currents are capable of moving bottom material for a short distance and redepositing it before the main current passes and without being incorporated into or mixed with material contained in the main current. A preturbidite shale 0.4 foot thick in the type section of the Kenwood is the thickest seen. Reverse grading, indicated by an upward increase in grain-size in the upper half of the bed is also seen in the Kenwood Hill section. Similar reverse grading has been reported from turbidites by Beall (1970, p. 490).

With the exception of reverse grading, preturbidites, and siderite associated with the zone of convolute bedding, the internal bedding sequence in siltstone beds of the Kenwood is typical of that attributed to turbidites by Bouma (1962, fig. 8). The internal sequence Bouma labelled T_a through T_e fits an experimentally produced bedding sequence made by deposition from a steadily decreasing flow regime (Simons, Richardson, and Nordin, 1965, fig. 21), where the basal part of the beds is massive and graded (T_a), overlain by planar horizontal laminae (T_b), in turn overlain by convolute or rippled laminae (T_c), succeeded by planar laminae (T_d), finally grading into a pelitic interval (T_e) (see diagram correlating the two, fig. 33).

Siltstone beds of the Kenwood that show most or all of this sequence were noted in two localities: along the Firetower Hill section in Bernheim Forest (loc. O, fig. 7), and along Pleiss Hollow section west of New Albany, Indiana (loc. B, fig. 7; pl. 6).

External sedimentary structures

The upper part of most of the beds appears somewhat more pelitic than the rest; locally the upper surface is ripple bedded. Most of the ripples internally show a uniform directional vector, but externally, the surface appears to be of a low amplitude compound or cuspate ripple. For the most part, however, the upper surface of the siltstone beds appears gradational with the overlying pelitic interval.

The basal surface is abrupt and planar, with the exception of fairly ubiquitous substratal marks. The substratal marks include casts of various impressions on the clay-rich slightly firm substrate of the siltstone beds. In order of abundance these casts include trace fossils of organic origin and marks made by tools and currents. The trace fossils are discussed separately. The most abundant tool marks are grooves, brush casts, prod, bounce, and roll marks. Less common among the substratal marks are current-produced markings, including current crescents, flute casts, ruffled groove marks of

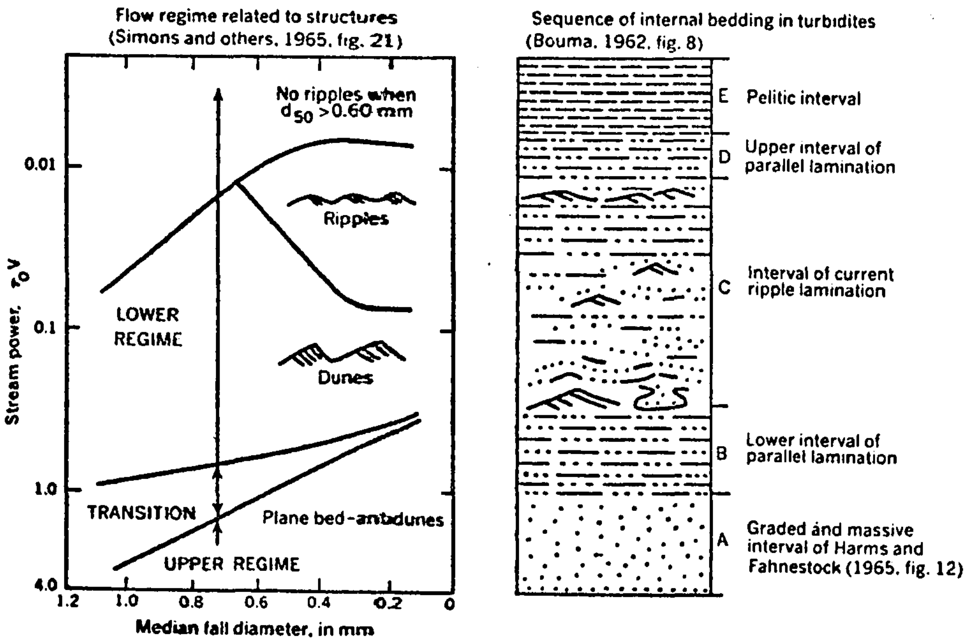


Figure 33. Flow regime related to structures in an ideal turbidite.

Dzulynski and Simpson (1966, p. 201), and furrow flute casts (See pl. 9).

Most of these structures are indicative of a certain degree of cohesiveness in the underlying shale sediment at the time the siltstone beds were deposited and are in accord with the diagram of Hjulström (1939, fig. 1), which indicates clays are cohesive to the extent that they require a higher velocity current for erosion to take place than the velocity required to erode silt.

Many of the substratal features are current-controlled. Some give an orientation, others a vector sense to the paleocurrents that influenced their formation, and will be treated more fully under a discussion of depositional environments and paleocurrents. A few beds show complete lack of sole marks; their contact with the underlying beds is planar and smooth.

Structures of organic origin

A variety of trace fossils appear on the upper and lower surfaces of the siltstone beds, within the beds, and in the shale between the siltstone beds. Martinsson (1970) suggests a toponomy for these occurrences as epichnia, hypichnia, endichnia, and exichnia respectively. Trace fossil classification according to probable activity of the organism making the particular trace led Seilacher (1953) to recognize five major categories: dwelling burrows (Domichnia), feeding burrows (Fodinichnia), feeding trails (Pascichnia), resting trails (Cubichnia), and crawling trails (Repichnia), as reviewed by Häntzchel (1962).

Trace fossils appearing on the base of the siltstone beds of the Kenwood (hypichnia) include grazing or browzing trails (Pascichnia) identified as Paleophycus and Nereites (?), and tunnel systems (Fodinichnia) identified as Lophoctenium and Planolites, and one that resembles Nereites, except that the plane of the pattern is normal to the bedding. In addition, several types of burrows were found for which no identification could be made from the available literature.

Among the epichnia are rare Zoophycos, more abundant Scalarituba, and Chondrites (all of which are Fodinichnia), and common straight trails tentatively attributed to orthoconic cephalopods. Within some of the siltstone beds, endichnia include the vertical borings, most of which are fairly straight and non-branching with slightly irregular walls, and in which a clay filling commonly weathers out to form a simple Scolithus-like hole, locally filled with a siltstone plug that is crescent-shaped in cross section. (See pl. 8.)

A complete catalogue of the ichnology of the Kenwood Siltstone Member is not attempted here. Most earlier workers in the Borden have noted "curly" worm marks, now assigned to Scalarituba (Conkin and Conkin, 1968) and Fucoids such as Taonurus caudi galli (Butts, 1915; Stockdale, 1931, 1939), now commonly referred to as Zoophycos. The more characteristic trace fossils seen include those in the following list.

Scalarituba missouriensis Weller 1899

Cosmorhaphe

Zoophycos Massalango 1853

Chondrites Sternberg 1833

Nereites Maclay 1839

Lophoctenium

Teichichnus

Paleophycos? Hall

Planolites

The ichnocoenosis of the Kenwood is shown in the diagrams (figs. 34 and 35). Representative photographs are included in plates 8 through 12.

The distribution density of trace fossils in the siltstone beds of the Kenwood is compatible with the turbidite origin suggested by the internal bedding sequence. The lack of borings and burrows near the base of the beds and the abundance of burrows near the top can be explained by rapid sedimentation of the siltstone relative to the shale. Such rapid sedimentation could have effectively buried the extant bottom fauna, some of which could have survived by escaping upward through the silt layers. Reestablishment of the epichnia was generally slow and was dependent on a relatively long interval of time under conditions of slow pelagic sedimentation. This is indicated by the lack of trace fossils throughout siltstone beds that are separated from overlying siltstone beds by only a thin seam of shale and the relative abundance of epichnia and endichnia in the upper parts of siltstone beds overlain by shale beds thicker than 0.5 ft.

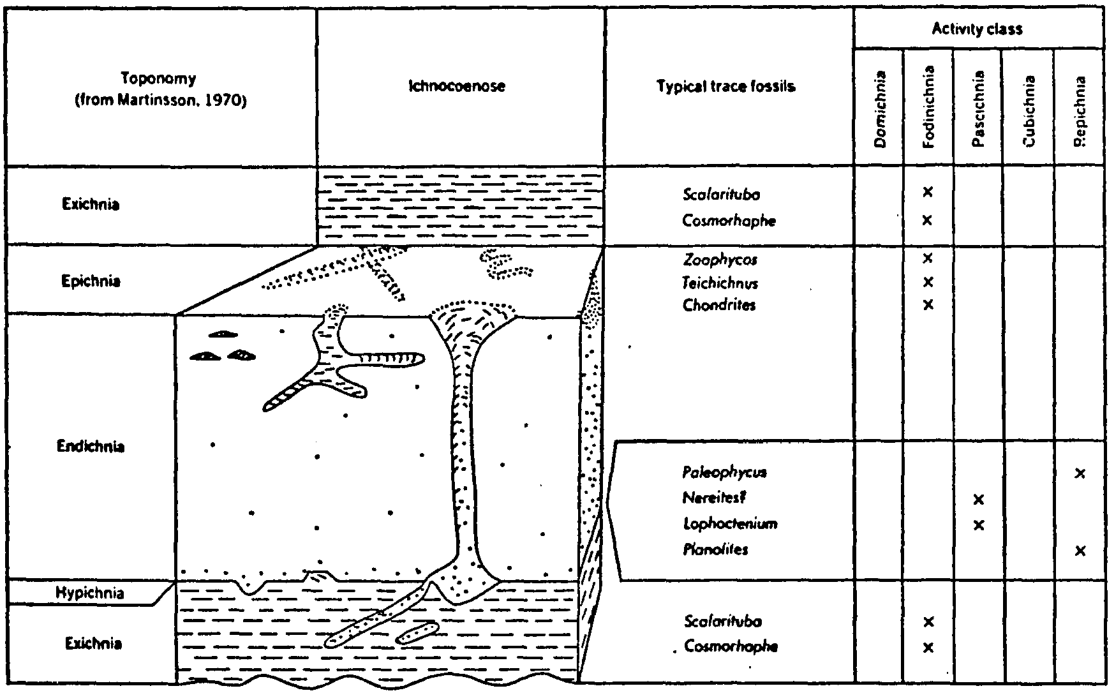


Figure 34. Diagrammatic classification of the trace fossils of the Kenwood according to toponomy and activity class.

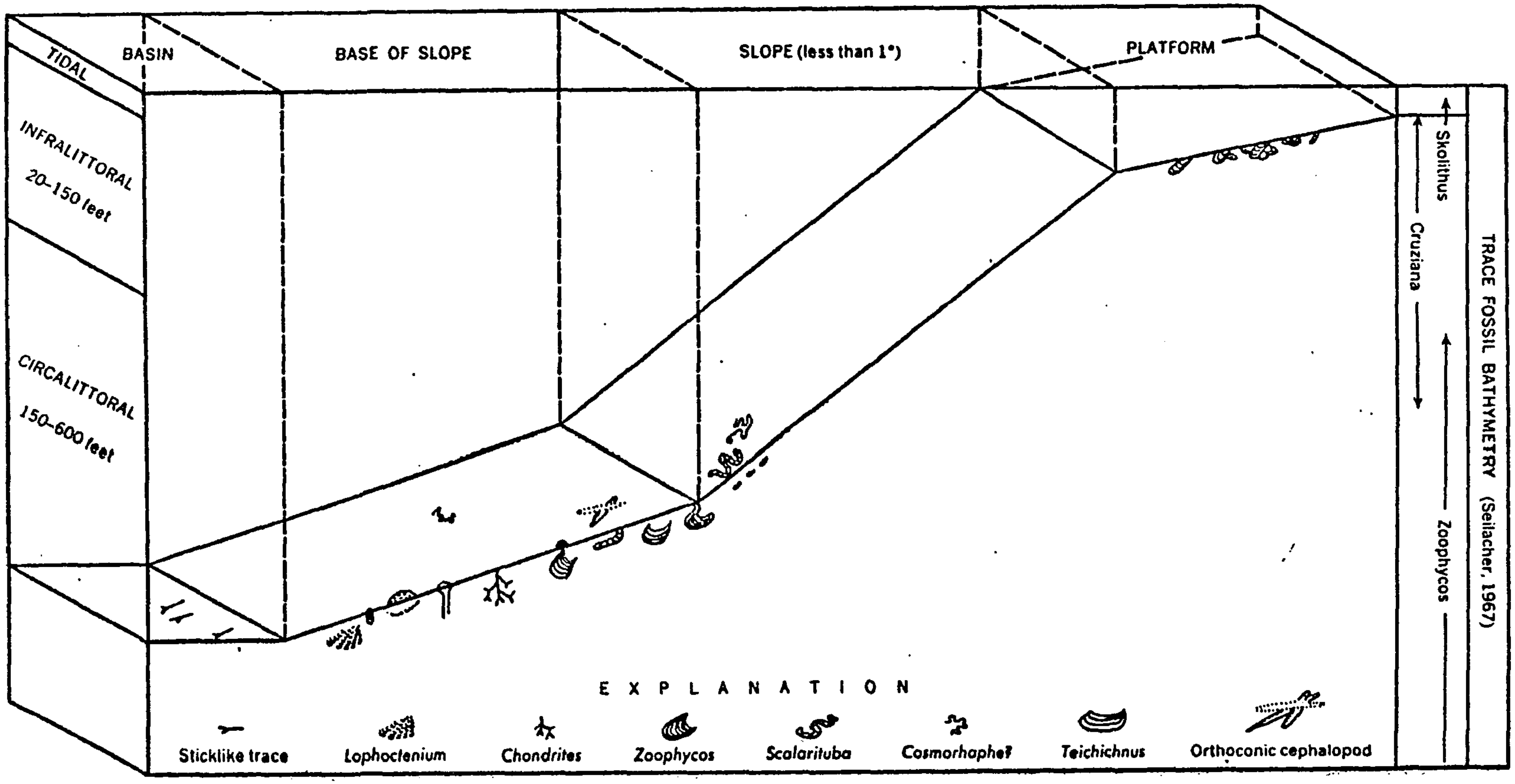


Figure 35. Diagrammatic ichnocoenose of the Borden delta front.

PROVENANCE

From the petrologic study of the Kenwood Siltstone Member, the following interpretation of the geology, relief, tectonics, climate, and distance to the source area is proposed.

The feldspar content of the Kenwood is shown by the triangular diagrams, fig. 21, as being significant to classification. This significance is shared by provenance studies. The freshness of some of the feldspar, the angularity of the grains, and the predominance of K-feldspar over plagioclase, as well as the sodic nature of the plagioclase indicate a source that likely was characterized by plutonic igneous rocks but included as well some sedimentary and metamorphic rocks. The fact that the feldspars show a wide range of weathering, and the immaturity reflected by the general angularity of grains and the high matrix content also indicate that the relief of the source area may have been moderately high. Hence, the source area must have been tectonically active. The presence of weathered feldspar indicates that the climate was humid in part, and the associated clayey sediment tends to confirm this.

The lack of coarser than very fine-grained sand in any of the Borden sediments in the study area indicates that the dispersal center was distant. The lack of maturity, additionally indicates that deposition was rapid. Folk (1968, p. 127) postulates that lack of maturity and rapid deposition are characteristics related to a tectonic arkose resulting in a clastic wedge.

Because the areal distribution of the samples is slight, the direction of the source area is best determined by means of the paleocurrent analysis discussed below. This indicates an easterly source of sediment. Eastern Canada as the source of the Early Mississippian Berea Sandstone in Ohio was postulated by Pepper, de Witt, and Demarest (1954, p. 95, 99), based on earlier studies by Young (1926, p. 83, 92-93). An eastern source for part of the Berea Sandstone is indicated by heavy mineral studies by Rittenhouse (1946). Pepper, de Witt, and Demarest (1954, p. 99) point out that the heavy minerals also preclude a granite-cored Appalachia as a direct source of the first generation sands in the Berea. Thus, it appears that the source of the Berea sands was not the same as that for the Kenwood, but that the siltstone of the Kenwood was possibly derived later from a granite-cored Appalachia.

An interesting comparison can be made with modern sands on the continental shelf off Long Island, the source of which may be similar to or even coincident with the granite-cored Appalachia. These sands, like the Kenwood, are largely subarkosic and, also like the Kenwood, the K-feldspar/plagioclase ratio is greater than 1 (McKinney and Friedman, 1970, p. 239). Apart from the Triassic intrusives, the terrane from which the Kenwood originated could well have included the same rock types that now contribute sediment to the shelf off Long Island.

PALEOCURRENT ANALYSIS

Detailed study of sedimentary structures provides the basis for interpreting the direction and intensity of the currents from which the sediments were deposited. The compilation and analysis of the data from the paleocurrents are essential to gaining a better understanding of the environment of deposition, the provenance of the sediments, and, ultimately, the paleogeography of the region.

Sedimentary structures in the Borden on the east side of the Cincinnati arch were identified as paleocurrent indicators by Rich and Wilson (1950), Rich (1950), and Wilson (1950). Since then, additional data have been provided for the Kenwood (Kepferle, 1968a, 1969, 1972a, b), the Farmers Siltstone Member (Moore and Clarke, 1970; Clarke, 1969), and the "Rockcastle freestone" beds of the Wildie Member of the Borden Formation (Weir, 1970). All of these studies indicate transport from east to west during early Mississippian Borden deposition.

Directional structures in ancient rocks are of two main types: one type indicates a line of movement and is termed linear; the other type indicates a direction of movement and is termed unidirectional (after Potter and Pettijohn, 1963, p. 4). Linear indicators in the Kenwood are more abundant than unidirectional indicators. Linear indicators include, in decreasing order of abundance, grooves, bounce, and brush casts on the base of the beds, and parting lineation and oriented fossils within the beds. Unidirectional indicators are rare in the Kenwood. They are less than 10 percent of the total current indicators measured, and include prod casts, load casts, flute casts, furrow flute casts (as used by McBride, 1962, p. 57), and chevron casts on the base of the beds, and ripple foresets and flame structures associated with internal convolutions within the beds. Unidirectional current indicators are sufficiently abundant to impart a general directional sense to the paleocurrents associated with the deposition of the Kenwood.

Flute, prod, and ripple foresets are considered the most directionally sensitive of the current indicators. Clasts showing imbrication and imbricated fossil fragments were seen in float. Drag casts, called chevron casts (Dunbar and Rodgers, 1957, p. 185), appear to have been formed by a tool being dragged across a pelitic bottom.

Flame structures have been attributed to penecontemporaneous drag during the formation of load casts. This may cause the tips of the flame structures to be bent in a down-current direction (Pettijohn and Potter, 1964, pl. 53B). Both upcurrent and down-current-directed flame structures, however, occur in a single bed within a few inches of each other in the Kenwood.

Channels in the Kenwood were not included with the grouped data because their orientation and continuity are too inferential.

Paleocurrent indicators are rare in the pre-Kenwood New Providence Shale Member in the study area. This paucity is due to the lack of good exposures and the absence of resistant non-pelitic beds requiring definitive current for transport. One quarry exposure of a small crinoidal accumulation about 25 feet stratigraphically below the Kenwood in the Brooks quadrangle shows oriented articulated crinoid stems, the alignment of which averages 295° - 115°. This alignment indicates that currents were operative during deposition of the shale, but that these currents were not necessarily similar in origin to those from which the Kenwood was deposited, inasmuch as they differ from the average Kenwood current indicators by about 50°.

All directional data for the Kenwood are treated as linear in the initial and summary groupings. Data are grouped according to subareas consisting of one-sixth of a seven-and-a-half minute quadrangle (table 7) and are summarized as a moving average map and current rose (fig. 36). Vector analysis of 37 unidirectional measurements is based on individual rather than grouped data, but is otherwise similar to the method outlined by Potter and Pettijohn (1963, p. 262-265). The resultant vector mean is 246° with a standard deviation of ± 51°. Confirmation of preferred orientation of 78° - 258° is shown for the linear data by the Tukey Chi Square Test, as outlined by Rusnak (1957, p. 53-54), using nine 20° classes from 0° to 180°). By comparison, the summary for the non-grouped linear data (n=526) indicates a mean of 67° - 247° with a standard deviation of ± 32°. Thus, the dominant paleocurrent system was to the west-southwest, normal to the strike of the Borden delta front. Paleocurrents parallel to the front were rare and possibly related to the fan origin postulated in the following section on the

TABLE 7

LINEAR DIRECTIONAL INDICATORS IN THE KENWOOD SILTSTONE MEMBER OF THE BORDEN FORMATION

Quadrangle and sector		Obser- vations	Linear mean	Vector length	Length in percent
New Albany	WC	3	83°	2.96	98.6
New Albany	SW	9	72°	8.79	97.7
Georgetown	SE	4	82°	3.96	98.9
Lanesville	NE	4	78°	3.96	98.9
Louisville West	NW	2	85°	1.99	99.6
Louisville West	WC	12	62°	11.84	98.7
Louisville West	SW	35	70°	34.08	97.4
Louisville West	EC	3	70°	3.00	100.0
Louisville West	SE	126	82°	87.27	69.3
Valley Station	NW	23	65°		
Valley Station	NE	19	62°	18.57	97.5
Valley Station	WC	6	59°	5.92	98.8
Valley Station	SE	4	42°	3.77	94.4
Valley Station	EC	1	50°	-	100.0
Brooks	NW	11	54°	10.72	97.4
Brooks	WC	41	56°	39.64	96.7
Brooks	SW	40	61°	38.20	95.5
Pitts Point	NE	1	50°	-	100.0
Shepherdsville	EC	20	86°	15.18	75.9
Shepherdsville	SW	14	53°	13.24	94.6
Shepherdsville	SE	57	89°	46.94	82.3
Samuels	WC	13	43°	9.96	76.6
Samuels	SW	45	85°	39.74	88.3
Lebanon Junction	SE	13	59°	9.64	74.2
Cravens	WC	19	16°	17.17	90.4
New Haven	WC	1	35°	-	100.0
Total		526	67°	168.36	31.9

Total standard deviation: ±32°

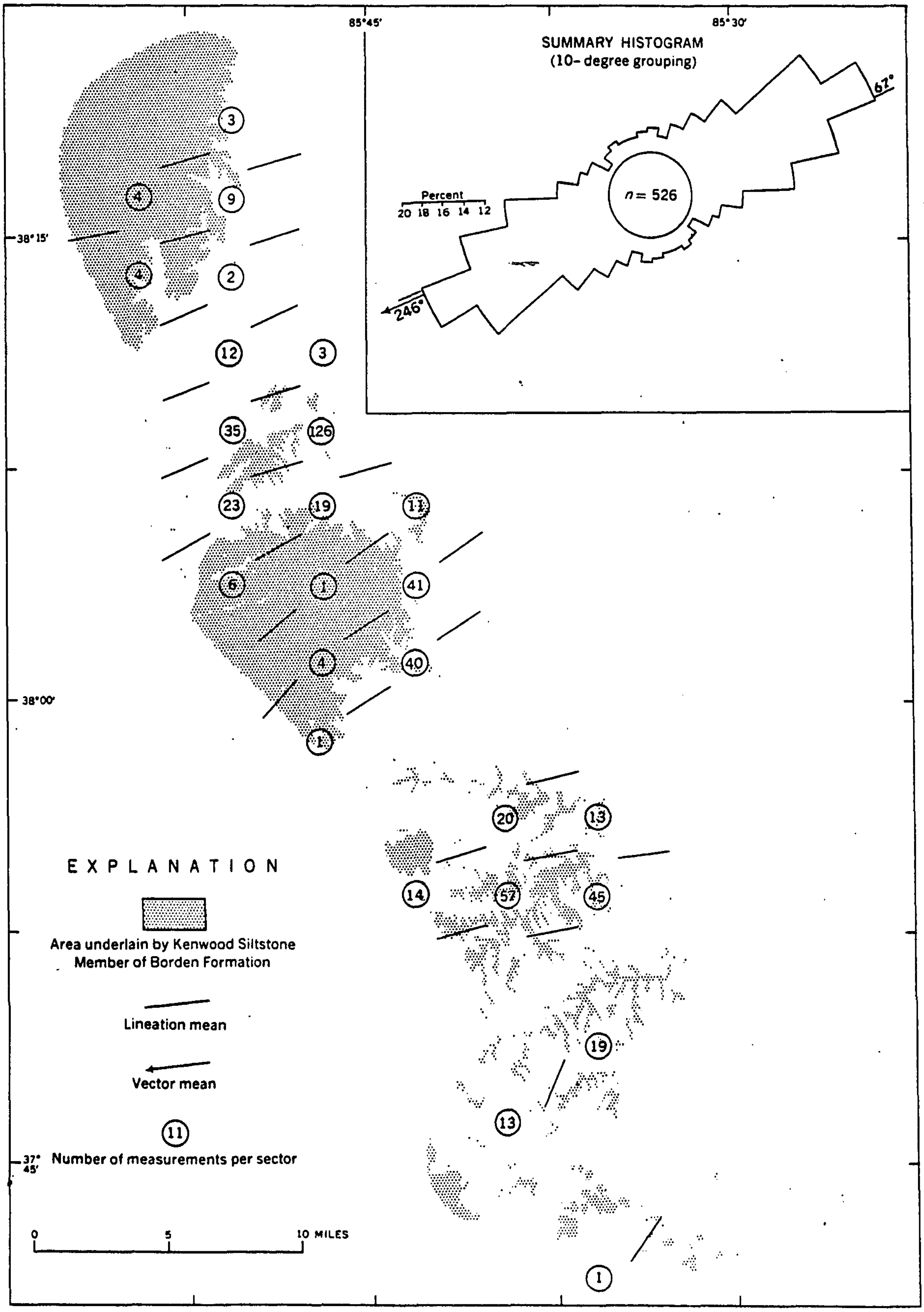


Figure 36. Moving average map and summary histogram of paleocurrent lineations and vectors, Kenwood Siltstone.

depositional model.

From the distribution of current sense on fig. 36, at least two local dispersal centers are postulated. Through upcurrent projection along the moving-average linears, one of the centers appears to have been located in what is now easternmost Jefferson County, the other in what is now western Spencer County, Ky. Vector means calculated for directional data from the two separate areas differ from each other by less than 2°. This suggests that the mode and amount of dispersion from both postulated centers was essentially the same.

DEPOSITIONAL MODEL

The siltstone beds of the Kenwood are believed to have been deposited from pulses of sediment in a series of turbidity currents, debauching fanwise from the edge of a prograding sediment platform of deltaic origin. The turbidite nature of these beds is indicated by a comparison of the geometry and petrology of the beds, their internal and external structures, associated fauna, and nature of the enclosing sediments, with a list of key features which characterize flysch deposits in ancient rocks (Cline, 1970, p. 89-91), as well as modern turbidites (Kuenen, 1964, p. 10 - 13). These key features are listed in table 8 in order of applicability to the Kenwood Siltstone Member.

Some of the features (items 17 through 25 and items 27 and 28) are mentioned only in relations to modern turbidites. Of these, items 18, 19, 23, and 24 are related to position of the individual bed and not so much its ultimate origin. Item 26 is mentioned solely in relation to ancient flysch. Only two of the listed criteria have not been recognized in the Kenwood: one is a correlation between bed thickness and maximum grain size; the other is the presence of plant remains. Both of these criteria are controlled by provenance. If the source contained no plant remains nor grains coarser than fine-grained sand, then plant remains and coarse grained sand could not be expected in the turbidite deposits.

Evidence supporting a turbidite origin for the Kenwood siltstone beds will be reviewed in the order in which the basic data are presented earlier in this report. Rather than repeat the citations of

TABLE 8

COMPARISON OF FEATURES THAT CHARACTERIZE TURBIDITES IN ANCIENT AND MODERN ENVIRONMENTS WITH FEATURES OF THE KENWOOD SILTSTONE MEMBER OF THE BORDEN FORMATION

Ancient and Modern Turbidite Characteristics (Cline, 1970, p. 89-91; Kuenen, 1964, p. 10-13)	Kenwood Siltstone		
	S[a]	P[b]	?[c]
1. Beds appear in alternating fine- and coarse-grained strata.	X		
2. The finer grained beds are mainly normal pelagic clay or shale, lacking all evidence of shallow water deposition.	X		
3. The finer grained interbeds tend to be uniform	X		
4. The original sediments in the coarser grained beds tend to be sand but may be as fine as silt or as coarse as conglomerate.	X		
5. The coarser beds are generally graded, but grading varies and may be obscure.	X		
6. Lower surfaces of the coarser beds commonly show sole marks	X		
7. The bases of these beds are abrupt; the tops may be somewhat less abrupt to gradational into the overlying shale.	X		
8. The sole marks have directional properties in which vectoral properties are less common than are linear.	X		
9. Where several beds are one above the other, the directional properties tend to be uniform for all the beds.		X	
10. Internal bedding shows the entire Bouma-sequence (Bouma, 1962) locally, with truncated base or missing parts more common than a complete cycle.	X		
11. The laminated divisions (T_b or T_d) are common in very fine sand and silt sized beds.	X		

[a] S = similar
[b] P = partly similar
[c] ? = no basis for comparison

TABLE 8 (Con't)

	S	P	?
12. Organic trails (trace fossils) may occur on the upper bed surfaces where gradation occurs and may be missing where beds are truncated or are immediately overlain by another turbidite with only a thin or missing shale interbed.	X		
13. Sorting is poor.	X		
14. Subaerial and shallow water features such as mud cracks and algal colonies are absent	X		
15. Shallow water fauna are absent except where displaced and incorporated into the coarser grained beds.	X		
16. Large-scale cross bedding is absent.	X		
17. The thickness of the beds may vary from a few millimeters to 6 meters.	X		
18. Nearly all deep sea sands are found on slopes of less than one degree.	X		
19. Mainly laminated structures, obscure grading, and common gradational tops characterize turbidites on basin floors.	X		
20. Mud may occur as lumps in beds.	X		
21. The character of the turbidite depends on the character of the source.			X
22. The sand or silt may be rich in feldspar, angular quartz, glauconite, mica, and pyrite.	X		
23. Thinner beds are farther from the dispersal center.	X		
24. Proximal beds show top-truncated Bouma-sequences and fewer fines than do distal beds.	X		
25. A lag concentrate of shells, one to two shells in thickness is found locally at the base of the beds.	X		
26. Thick stratigraphic sequences have vertical changes in bedding style resulting from thickness variations in shale, sandstone, or both.	X		
27. Bed thickness shows a strong correlation with grain size.			X
28. Plant remains are present to abundant.			X

Cline (1970) and Kuenen (1964), supportive evidence from modern and ancient turbidites listed from these two authors in table 8 will be cited by item number in parenthesis.

Evidence from stratigraphy

Stratigraphically the Kenwood is part of a mass of sediments that has been attributed to deltaic origin (Swann and others, 1965; Lineback, 1966, 1968a; Peterson and Kepferle, 1970). Recent investigations of modern deltas have disclosed turbidites as part of the pro-delta cone (Ewing and others, 1958; Shepard, 1951, Phleger, 1951), although notable divergent interpretations have also been presented (Huang and Goodell, 1970; Greenman and LeBlanc, 1956, p. 841). One might expect, therefore, to find turbidites in some form in the ancient analog of the modern delta. At the risk of imparting a circular aspect to the reasoning, it is suggested that the Kenwood epitomizes the turbidite facies of such a deltaic environment.

Many of the citations of Cline and Kuenen seem applicable to the Kenwood, and indicate a turbidite origin for its siltstone. In common with ancient and modern turbidites, the siltstone beds of the Kenwood appear in alternation with the finer shale beds (1). The shale beds lack all evidence of shallow water deposition (2), and show little change in bedding and composition from that of the underlying New Providence (3).

The thickness of the siltstone beds ranges from less than 0.1 foot to as much as 20 feet and averages about 0.5 foot (17). The siltstone beds are thickest near the dispersal centers inferred from paleocurrent data, and are thinner distally (23). This is true also for the overall geometry of the Kenwood, which is thickest near the postulated dispersal centers. The slope on which the siltstone beds were deposited was generally less than 1° (18) and is regarded as representative of the slope on the sea bottom during the time of deposition.

The episodic nature of turbidity currents is brought out by the limited number of turbidite beds in the Kenwood relative to the hundreds of beds described in most turbidite sequences (Walker, 1970; Snavely and others, 1964; Hsu, 1969; Cline, 1970; McBride, 1962; Enos, 1969; Kimura, 1966; Nederlof, 1959). The episodic nature is also brought out by the vertical changes in bedding style within the Kenwood.

Number of beds

The fewer than 40 beds within a vertical sequence of the Kenwood indicate a triggering mechanism of short duration and moderately intensity, be it seismic shock, storm, hyperpycnal currents, or simply oversteepening along the upper margin of the slope. The absence of siltstone beds in the shale represented by the New Providence further corroborates the episodicity of this deposition, thereby implying a special and somewhat unique event on the Early Mississippian craton. (This is discussed further on p. 125).

Bedding sequence, external

Changes in bedding style have been used by Dzulynski and Walton (1965, p. 3) to define facies within flysch sequences: equal proportions of turbidites and shale have been called normal flysch; where shale predominates, shaly flysch; where turbidites predominate, sandy, flysch; and where exotic clasts and slumps are abundant, wild-flysch. Such terms appear inappropriate inasmuch as the Kenwood is not considered as a flysch sequence.

The Kenwood cannot be classified as flysch because certain characteristics associated with deep sea turbidites are not present. Characteristics of deep sea turbidites and flysch deposits which are listed by Kuenen (1964) and Cline (1970), but which are not considered diagnostic for a turbidite origin of the siltstone beds in the Kenwood are the extremely thick accumulations of turbidite sequences and the appearance of slumped beds, or fluxo-turbidites. Both characteristics may be considered as measures of the tectonic activity that commonly accompanies turbidite deposition. The lack of these features preclude classifying the Kenwood as flysch, for Hsu (1970, p. 9) recommends:

> Flysch, as a term for a recurrent facies, includes marine shales with alternating sandstone and/or some impure limestone layers, which constitute a well-bedded sequence in an alpine-type mountain chain with a tectonic setting, and sedimentological features similar to the Alpine Flysch in its more typical development.

Cline on the other hand, (1970, p. 89) quotes Sujkowski (1957, p. 544):

> the name flysch is a facies denomination for a marine deposit composed of innumerable alternations of sharply divided pelitic [argillaceous] and psammitic [fine-grained clayey sandstone] layers. Other rocks in the deposit are accidental, and in particular pure limestones are rarely present. The series commonly attain thicknesses of thousands of feet and were deposited in geosynclinal areas.

In no sense does the setting of the Borden Formation appear to match the magnitude of the tectonic setting attributed to flysch. The basin in which the Kenwood turbidites were deposited was neither rapidly sinking nor near a tectonically active highland. Instead of a trough configuration describing the basin, a better description might be that of a shallow, differentially subsiding shelf onto which a deltaic mass prograded.

Bedding style has been used by others to define facies, which in turn were used to define proximality of turbidites (Parea, 1965; Warren, 1963; Kimura, 1966; Walker, 1967, 1970), but no names have been applied to these facies. Classes of bed packages proposed by Thomson (1971) and discussed on p. 42, on the other hand apply to turbidite sequences and may be applied to the Kenwood (26).

Evidence from petrology

Compositional and textural similarities between the Kenwood and known turbidites would seem logically to be independent, as they are governed mainly by the source of the sediments (21). In common with turbidites, however, the Kenwood silt is rich in feldspar, angular quartz, mica, and pyrite, and contains traces of glauconite (22). A lag concentrate of shells found in at least one locality in the basal part of a siltstone bed is a characteristic found in other turbidites (25), as is the occurence of mud galls in the base of another Kenwood siltstone bed (20).

Texturally, the original sediment in the coarsest beds is mainly coarse silt (4), for which sorting is poor (13). No correlation was found between bed thickness and grain size (27). As mentioned earlier, this appears to be a factor that is affected by the source of sediments (21) and may simply indicate that the immediate source was chiefly silt.

Internal sedimentary structures

The importance placed on internal structures in ancient and modern turbidites (table 8, items 5, 10, 11, 16 and 19), warrants further discussion of grading, the pelitic interval (T_e), incomplete sequences and internal porosity in the Kenwood.

Grading--The basal massive layer (T_a) is commonly referred to as the graded layer, but in fact, the entire bed may be graded in the sense of Kuenen (1953, p. 1049): "The lower, main part of a graded bed is generally massive . . . The upper part is slightly or distinctly laminated." Obvious grading is rarely observed in the Kenwood because of the minute variations in grain-size present in the siltstone. Size analyses, however, indicate an internal grading of an entire bed, defined mainly by the percent of the coarsest fraction measured in a given bed. A comparison of cumulative curve parameters of grain size analyses from samples from the basal, middle, and uppermost parts of nearly every bed so far examined shows this grading. A comparison of median grain size also shows the same fining-upward tendency, but the upper parts of most of the beds are gradational with the overlying pelite of the T_e sequence, and contain additional clayey material introduced as burrow fillings. (See photomicrographs of thin sections, pls. 2 & 3, and of the upper surface of beds, as well as the grain-size data, table 1).

The pelitic interval.--In the Kenwood, the siltstone beds represent the turbidites (T_a through T_d); the shale interbeds represent the tails of the turbidity currents (T_e) and the mud (pelite) accumulation generally attributed to pelagic sedimentation. Determination of the extent of the T_e interval is clearly arbitrary. That more of the pelites may actually be of turbidite origin than hitherto supposed has been suggested by Enos (1969, p. 713). This suggestion is supported by evidence in the Kenwood and New Providence members by the association of the sideritic ironstone concretions with silty laminae in the shales, in which the laminae and the zone of accompanying concretions appear to be continuations of the individual turbidite beds. Most of the shale probably belongs to the pelitic interval, but criteria are lacking for the satisfactory identification of interval T_e where it is followed by continuing pelitic sedimentation. Most measured sections identify only the somewhat cemented and resistant siltstone beds as belonging to an individual turbidite. Techniques to enable the identification of the T_e interval remain to be developed. The occurrence of siderite nodules within the shale zones is suggested as one possible indicator of the presence of the T_e interval where the basal part of the sequence (T_a through T_d) may not have been deposited.

Incomplete sequences and proximality.--Most of the siltstone beds of the Kenwood begin with the T_b planar laminated sequence, which has been recognized as a common phenomenon in many turbidites (Table 8, items 10, 11, and 19). In general, however, the bedding in the siltstone of the Kenwood is too obscure and the beds too few to enable the discrimination of proximal and distal environments (Bouma, 1962, p. 98-99; see fig. 37) or Walker (1966a, b, 1967, 1970). The proximality of the Kenwood siltstone beds must be based on geometry and external features summarized in table 9.

Internal bedding and porosity.--Investigators of porosity of turbidite beds have found the highest values near the middle of the beds (Alan Thomson, personal communication). If, as is suggested earlier in this report, the occurrence of sideritic zones in the middle of the siltstone beds of the Kenwood is related to zones of higher initial porosity in the beds, a hitherto unrecognized corroboration of a turbidite origin is provided for the Kenwood.

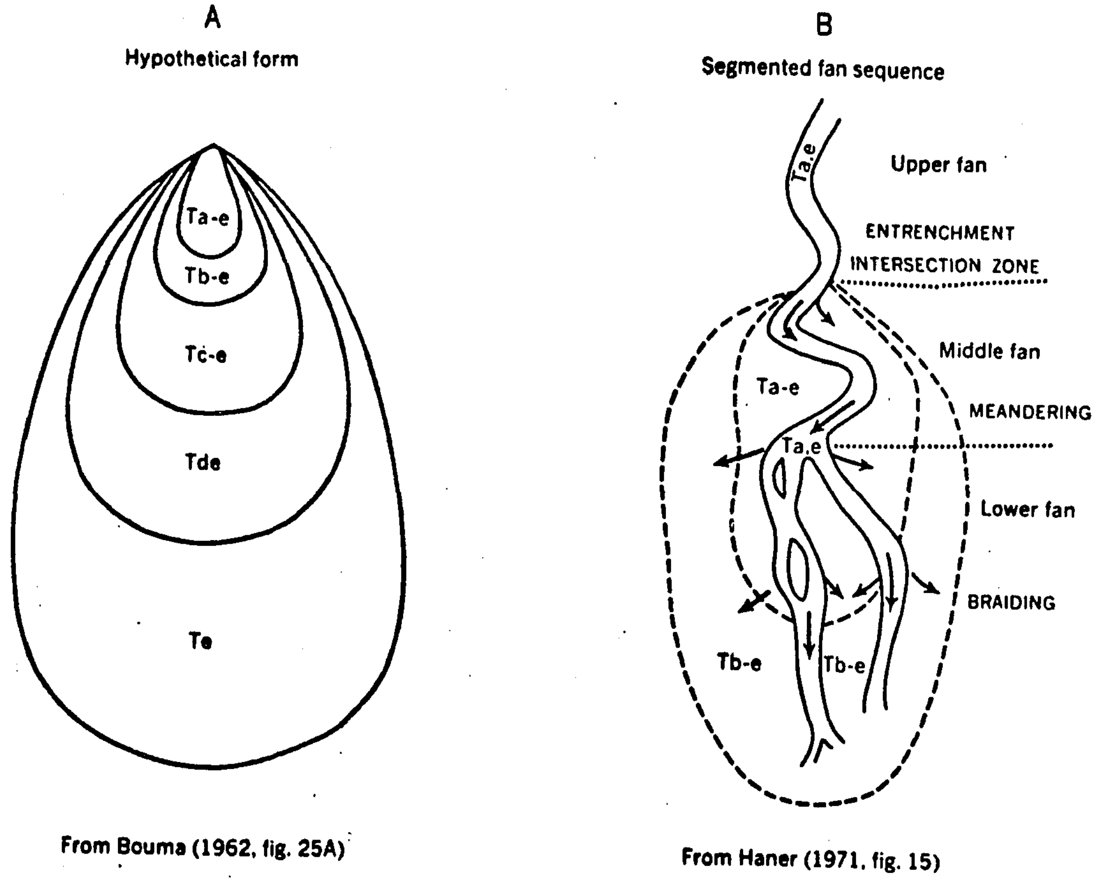


Figure 37. Variation of internal bedding sequence in turbidites according to position on subsea fan.

TABLE 9

COMPARISON OF PROXIMAL AND DISTAL TURBIDITES, KENWOOD SILTSTONE MEMBER, BORDEN FORMATION

PROXIMAL	DISTAL
A. Beds thick, as much as 20 ft.	Beds thin, one exception
B. Beds of mainly silt grains	Beds of mainly silt grains
C. Individual beds amalgamated	Individual beds not amalgamated
D. Beds irregular in thickness	Beds fairly uniform in thickness
E. One washout, five channels	No washouts, no channels
F. Mudstone partings thin, occasionally poorly developed or absent; siltstone/shale ratio high	Shale partings well developed, siltstone/shale ratio low
G. Beds content graded	Beds content graded
H. Base of siltstone always sharp, top often sharp; rare T_{a-e} sequences	Base of siltstone always sharp; top often sharp; T_{a-e} sequences absent
I. Laminations common, ripples rare	Laminations common; ripples absent
J. Scour marks present; tool marks common	Scour marks absent; tool marks less common

Listed successively after Walker (1967, Table 2)

A possible explanation for higher porosities in the middle of turbidite beds may be related to the internal bedding sequence; more specifically, to the zone of convolute bedding and ripple lamination (T_c). The bedding sequence, in turn, has been demonstrated to be related to the flow regime of the depositing currents (Harms and Fahnestock, 1965, p. 109). A reason given for the occurrence of deformed zones within sand units is the increase in shear stress (Sanders, 1960, p. 460; Dott, 1963, p. 108; Coleman and Gagliano, 1965, p. 139) in the transition from the upper flow regime to the lower flow regime, resulting in high pore pressure and imparting a "quick" nature to the sediment. Thus, the turbulent flow conditions at the boundary between the two regimes produces a brief state of high disorientation without normal dewatering of the sediment. The sediments deposited during these conditions should have higher porosity and permeability than is found in the overlying or underlying sediment. Such a mechanism would account for the localization of sideritic zones in the middle of the siltstone beds of the Kenwood.

Iron sulfide.--Basal iron sulfide in turbidite sequences has been reported by Frank Simpson (written communication, 3 July 1970). Basal iron sulfide concentrations in the Kenwood siltstone beds is corroborative of a turbidite origin for the beds. The reason for the selective occurrence in the basal part of the basal bed, according to Simpson, is that the depositing currents picked up sulfide concentrations from the ocean bottom and concentrated them in the density current. If Simpson's hypothesis is correct, then the sulfide concentration in the beds should be graded, diminishing in abundance upward within the beds. This is exactly the pattern shown by the sulfide occurrence in the basal siltstone bed at the Kenlite quarry section.

The problem of the origin of such sulfides on the sea bottom has been reviewed by Love (1969), who indicates that sulfides are diagenetically concentrated below the sediment-water interface following the action of sulfur-producing bacteria. Love further reports that framboidal and single microscopic grains of pyrite are forming in this way today in The Wash.

A further problem such an explanation raises in regard to the occurrence of pyrite in the Kenwood, however, is why the pyrite is concentrated only in the basal bed of a sequence. The turbidite origin of the siltstone beds provides a tentative answer. The first of a series of turbidity currents might concentrate this pyrite and at the same time sweep the sea bottom clean of extensive sulfur-producing bacteria. This clean sweep, then, would be sufficient to prevent the reestablishment of the bacteria population so long as the currents continued at periodic intervals from the same source area.

External sedimentary structures

In common with ancient and modern turbidites, the Kenwood siltstone beds have abrupt bases that commonly show sole marks (table 8, items 6 and 7). Because the sole marks are molds of the surface on which the beds were deposited, they are an indication of the flow regime of the depositing current. As such, sole marks are also indicators of the distance from dispersal centers of the currents (Walker, 1967). Currents not capable of scouring the bottom sediment result in the preservation of the traces of bottom fauna such as tracks, trails, and burrows. Currents of higher flow regimes are capable of planing off, scouring by flutes, or even channeling the underlying sediment.

Inasmuch as the highest flow regime attained by a turbidity current is likely reached at the foot of the slope on which the current was generated, flute casts are reported by Walker (1967) to be more prominent in proximal turbidites; whereas grooves perdominate in distal turbidites. Substratal groove casts are common throughout the siltstone beds of the Kenwood. Flute casts are common mainly in the eastern exposures, and there some of the thicker beds show completely smooth basal surfaces. The presence of flutes may indicate beds deposited under conditions of the upper flow regime, whereas the presence of only grooves may indicate deposition under conditions of a somewhat lower flow regime. Hence, an eastern source for the depositing currents is indicated by the type of sole marks in the Kenwood as well as by the directional structures of the sole marks.

The flow regime in itself is the result of a complicated interplay of such factors as velocity, viscosity, water depth, and thickness of the effective moving flow, as is pointed out by Harms and Fahnestock (1965, p. 109). Other turbidites seem to substantiate this observation, for Enos (1969, p. 718) reports that some 1-cm-thick beds show abundant flute casts at the base, whereas beds more than 50 cm thick commonly have featureless bases. Thicker flows must in some way plane off the substrate, for the bases of the thicker Kenwood siltstone beds, like those reported by Enos (1969), are completely smooth, preserving neither flutes, grooves, nor molds of pre-existing trace fossils.

All gradations of substrate planation have been observed in the Kenwood. Some trace fossil burrow rims show truncation by brush casts or grooves, indicating that the burrows were formed before the siltstone beds were emplaced. Other trace fossils were emplaced following deposition of the siltstone, as is indicated by destruction of the current-scoured or tool-marked surface by trails made by browzing or burrowing organisms. The latter is observed in the more distal beds of the Kenwood.

Basin Geometry

A partial picture of the geometry of the basin in which the Borden was deposited is inferred from the geometry and the paleocurrents of the lithostratigraphic subdivisions of the Borden. A comparison of the trend of the paleocurrents relative to the geometry of the turbidite-bearing units has been applied in determing whether a given sequence is basin marginal or a trough deposit, or some combination of the two (Walker, 1970, p. 223-227). Paleocurrents dominantly parallel to the long dimension of the turbidite unit, indicate a trough fill; paleocurrents perpendicular to the long dimension of the unit indicate a basin-marginal fill. The west-southwest trend of the paleocurrents in the Kenwood are perpendicular to the north-northwest trend of the areal extent. This indicates that the Kenwood is a basin-marginal rather than a trough-filling turbidite sequence.

The northwestward trend of the basin margin during the deposition of the Kenwood is corroborated in the Lower Mississippian sequence of central Kentucky by the configuration of at least three other stratigraphic features: the Holtsclaw Siltstone Member of the Borden Formation, the Knifley Sandstone Member of the Fort Payne Formation, and the Borden delta front - the boundary between the Borden and the Fort Payne Formations (fig. 6). These features, like the Kenwood, exhibit depositional and stratigraphic fall-off to the west-southwest (Hrabar and others, 1971; Sedimentation Seminar, 1972, in press). The fact that the Kenwood is older than any of these other features implies that the general orientation of this part of the basin persisted throughout most of the Early Mississippian with little variation.

Adding a vertical dimension to the basin geometry from stratigraphic relief of the Kenwood amounts to about 250 feet (figs. 13 and 14). The stratigraphic relief registered in the Knifley and the Holtsclaw members, on the other hand, is generally less than 130 feet. Some of the difference between the relief of the Kenwood and that of the other two may be related to a progressive shallowing of the seas following deposition of the Kenwood. Whether this relief represents the entire sea bottom, or a specific portion of the relief along the Kentucky-Indiana portion of the Early Mississippian basin requires the analysis in greater detail of a possible turbidite model that best explains the Kenwood depositional environment. This analysis should also involve the total stratigraphy of the Borden, the proper interpretation of the environmental indicators within the Borden in its tectonic framework, and the application of Walther's Law. From information developed to this point, the basin appears to deepen an unknown amount to the southwest with the margin oriented roughly north-northwest during the deposition of the Kenwood turbidites, which were deposited along the margin of the basin.

Subsea Fan Model

Submarine canyons long have been considered an appropriate environment for the occurrence of turbidity currents; the probable depositional sites of turbidites, logically, was assumed to be the subsea fan at the mouth of the canyon (Ericson and others, 1952; Bates, 1953). Sampling programs have substantiated this (Gorsline and Emery, 1959; Emery, 1960; Bouma, 1964; Bouma and Shepard, 1964; Shepard, Dill, and von Rad, 1969; Piper and Normarck, 1971). Although some of the findings concerning modern and ancient subsea fans are applicable directly to the Kenwood, many of the characteristics of these fans are not represented clearly in the Kenwood. For the sake of simplicity, these characteristics come under the broad headings of location, geometry, fabric, sedimentary structures, and fossil content (table 10).

TABLE 10

CHARACTERISTICS OF MODERN AND ANCIENT SUBSEA FANS RELATIVE TO THE KENWOOD SILTSTONE

Modern and Ancient Fans	Kenwood		
Characteristic	Similarity		
	Yes	No	?
Location:			
1. Base of slope	X		
2. Common at mouth of submarine canyon			?
3. Large where canyon heads near shore			?
4. Small where canyon heads far from shore			?
Geometry:			
5. Fan shaped	X?		
6. Thickest near apex	X		
7. Surface concave up near apex,	X?		
convex up distally	X?		
8. Gradient 3° near apex,	X?		
merges with basin distally	X		
9. Radius 10-15 km	X		
10. Thickness ranges into thousands of feet		X	
Sedimentary structures, fabric, and fossils:			
11. Sedimentary structures vary with location	X		
12. Current structures in pattern radiating from apex	X		
13. Channels present, more numerous proximally	X		
14. Channels tend to radiate from apex	X		
15. Definite downslope decrease in grain size		X	
16. Benthonic fauna rare or absent with exception of trace fossils	X		

Characteristics

Location (Table 10, items 2, 3, 11, and 12).--A characteristic of large subsea fans is that they are found at the base of slope at the mouths of submarine canyons, or lie in front of major river deltas as sediment cones. Smaller fans have been pointed out by Sullwold (1961, p. 71) at the mouths of shorter canyons. Because of loss to recent erosion, the source canyons or source delta of the Kenwood siltstone are no longer preserved in the geologic record, but if they were canyons, they would likely be insignificant, perhaps on the order of one one-hundredth that of present submarine canyons, judging from their geometry. From the depositional dip, however, the Kenwood can be attributed to the base of slope environment similar to that for modern fans. This replaces the model proposed by Rich (1950, fig. 1, p. 718) who attributed the bedding features characteristic of turbidites to the slope environment rather than the base of slope.

Geometry (table 10, items 1, 8, 9, 13, 14, and 16).--The fan shape of the areal distribution similar to that of modern fans and sediment cones is obscured in the Kenwood by the coalescing of two penecontemporaneous fans that serve to make up a single litho-stratigraphic unit. This is comparable, however, to the Miocene Tarzana fan in California, for which Sullwold (1960) used upslope projections of paleocurrent data to locate the paleo-apex. In common with modern fans (Haner, 1971), the Kenwood tends to thicken towards the apices (fig. 8), and cross sections (fig. 14) suggest that the paleosurface may have been concave up near the apex and convex up distally. Because the extreme proximal beds of the Kenwood are no longer preserved in the section, the gradient near the apex can no longer be determined; most certainly, in common with modern fans, the gradient merges with the basin distally, as is demonstrated by the asymptotic distal approach of the Kenwood to the underlying New Albany Shale. The remaining radius of the Kenwood, 10 miles (15 km) is within the 10-15 km radius characteristic of modern fans.

The greater discrepancy between the Kenwood and the ancient and modern subsea fan model, however, is that the thickness of the turbidite accumulation of the Kenwood is less than 100 feet, whereas the total accumulation of turbidite sequences in both the ancient and recent are commonly one or two orders of magnitude greater (The Pliocene turbidite accumulation in the Ventura Basin of California is about 13,000 feet thick [Emery and Bray, 1962]). Much of this large-scale accumulation, however, has been atrributed to the growth of the fan by incision and headward erosion of the canyons following faulting along the continental margin (Haner, 1971). Repeated faulting along a well-defined zone over a long period of time has resulted in the tremendous thicknesses of turbidite accumulations in the basins. The corollary to this is that without continued tectonic activity, basin filling by turbidites is short-lived and sediment will not accumulate to great thickness. The Kenwood, therefore, cannot be fitted to the tectonic fan model as proposed by Haner (1971).

Fabric, sedimentary structures and fossils (table 10, items 4, 5, 6, 7, 10, and 15).--Distribution of the typical Bouma-sequence of internal bedding structures has been suggested by Haner (1971) to follow a significant pattern in the modern subsea fan (fig. 37). As mentioned previously, however, little variation is found in the bedding structure of the Kenwood. The sequence T_{be} is most abundant in the Kenwood. Sequences T_{bcde} and T_{abcde} are extremely rare, and other combinations are not observed, with the possible exception of a questionable T_{ae} sequence.

Additionally, Walker (1967) has emphasized that channels are requisite characteristics of subsea fans. Although the orientation of channels in the Kenwood has not been outlined with clarity sufficient for inclusion in paleocurrent data, the presence of channels in the proximal part of the Kenwood is in accord with the fan models of both Walker (1967) and Haner (1971). Data on variation in grain size in the Kenwood are likewise insufficient to evaluate a definite downslope decrease in grain size found in modern fans. This, however, may be owing to the nature of the material included in the turbidity current and may not be a significant parameter when dealing with predominantly siltsize turbidites.

The nearly complete lack of all but trace fossils in the Kenwood compares favorably with evidence from modern subsea fans.

Revised Subsea Fan Model

The Kenwood turbidites appear to be a special case of a subsea fan, requiring modification of the existing model to fit the particular process-response factors it embodies. Because the lithology and geometry of the Kenwood is repeated areally and possibly vertically in the Borden in at least three additional units--the Farmers Siltstone Member *, the "Rockcastle freestone" beds of the Wildie Member, and the Lampkins Sandstone in the Indiana outcrops--a modified subsea fan model is proposed to aid in deciphering the details of their paleographic setting.

---

* Moore and Clarke (1970, p. 213) confirm the suggested turbidite nature of the Farmers Siltstone (Kepferle, 1968) and delineate a westward-facing paleoslope in water ranging in possible depth from 675 to less than 100 feet based on earlier estimates of the environment of deposition proposed for the Chattanooga-Ohio-New Albany Shale below the Borden. They avoid speculation, however, concerning possible factors initiating the turbidity currents on these slopes.

The "thin" subsea fan model proposed here for the Kenwood was built from a dispersal center that was short-lived geologically. This negates persistent episodic fault movement, but doesn't preclude faulting and earthquakes as mechanisms for triggering turbidity currents. If submarine canyons are cut by turbidity currents, and evidence from recent canyons suggest that they are, then the lack of a large number of turbidites would indicate that erosional canyon development, too, was short-lived. Curray (1969, p. JC-VI-16) suggests that, "canyons are most common during period of rapid eustatic fluctuations to sea level, as in the Quaternary, or in orogenic rather [than?] epeirogenic continental margins."

Not all base-of-slope turbidites are related to subsea fans. Bornhold and Pilkey (1971) have traced bioclastic limestone turbidites in the Columbus Basin off the Bahamas without reporting a fan geometry. Two major transport directions are reported, but the turbidity currents are assumed to have originated in the upper parts of steep slopes surrounding the basin. Meischner (1964, p. 165) concludes that the turbidity currents of the "Allodapische Kalke" are triggered simultaneously over a broad area. Thomson and Thomasson (1969, p.77) suggest that the turbidites of the Dimple Limestone lie partly on the basal slope as well as on the basin floor.

Assignment of a given turbidite-bearing sequence, therefore, should be made to the process-response model to which its characteristics bear the greatest similarity. I suggest that more such sequences than have been recognized are assignable to the thin subsea fan model.

The thin fan model in itself lacks indications of distance from the shore or depth of the water. Creation of a fan-shaped body would require a dispersal point such as a distributary channel down which sediments were introduced to the shelf floor and down which the turbidity currents came episodically. Indications of distance from the shore and some measure of depth may be gained by examining the stratigraphic relationships in reference to the vertical profile (Visher, 1965).

Triggering mechanism

Turbidity currents can be generated in a number of ways. Among those ways considered here are storm surges (Daly, 1936; Passega, 1962), floods (Heezen, 1956), over-steepening of slopes (Terzhagi, in Mathews and Shepard 1962; Huang and Goodell, 1971), hyperpycnal flow (McBride and others, 1971), and seismic shock (Gutenberg, 1939; Heezen and Ewing, 1952, 1955; Heezen and Drake, 1964; Ryan and Heezen, 1955; Ambraseys, 1960; Houtz, 1962; and Coulter and Migliaccio, 1966). Attempts to generate turbidity currents in natural environments by resedimentation have been futile (Buffington, 1961), although Morgenstern (1967) sets forth mathematical requirements of the Chezy equation to explain why Buffington's experiments were inadequate. Possible generating mechanisms are reviewed below in an effort to find the one that best explains the number and character of turbidites in the Kenwood. In this review, the intensity is deemed a factor influencing the thickness of the individual turbidite bed, the interval between occurrences is believed to be reflected in the respective thicknesses of the successive pelitic interbeds; the frequency of occurrence is also reflected in the total number of turbidites in a sequence. The results are summarized in table 11.

Storm surges, in order to generate turbidity currents, are expected to reach a certain level of intensity before the current forms (Passega, 1962, p. 116). Successive turbidites, therefore, should be of nearly equal magnitude in a given locality. Their occurrence should be cyclic and relatively frequent, resulting in tens to hundreds of uniformly thin beds. Recurrence at intervals ranging from 1 to 100 years would be likely. Such an explanation does not account for the small number -- and wide range in thickness of the siltstone beds in the Kenwood. Storm surges, therefore, are rejected as the triggering mechanism of the Kenwood turbidites.

Floods bringing sediment-laden water into the ocean have been described (Heezen, 1959) as another generator of turbidity currents. Currents thus formed should occur with the same frequency and intensity as those from storm surges. Floods, therefore, are also rejected as a triggering mechanism for the Kenwood turbidites.

Hyperpycnal flow at the delta front is attributed to have been the generative mechanism for a group of prodelta turbidites in rocks of Late Cretaceous age by McBride, Weidie, and Wolleben (1971). The thickness of the turbidite group they describe indicates that this mechanism is uniform, repetitive, and cyclic, with a probable frequency of about that suggested for floods and storm, 1 to 100 years. Hence, hyperpycnal flow, too, is rejected as a triggering mechanism for the Kenwood turbidites.

Both oversteepened slopes and seismic shock, together or separately, have been found to cause landslides that, in the subsea environment, develop into turbidity currents. Oversteepened slopes have been cited as probable causes of slumps on the Fraser Delta (Mathews and Shepard, 1962), and on the Mississippi cone (Huang and Goodell, 1971) on the basis of bathymetry. Terzhagi, in Mathews and Shepard (1962), suggests that unconsolidated sediment on slopes as gentle as 2° may fail, Shepard (1955, p. 1497) postulates failure on slopes as slight as 1/2°. Such oversteepening at major dispersal centers might be expected to take place over fairly short periods of time. Although subject to the vagaries of dispersal currents, they could be episodic as well as cyclic. The magnitude of the turbidity current might tend to vary slightly. Recurrence at intervals of from 10 to 100 years may be conservative. Although slopes in the study area are postulated to have exceeded 1° locally, most were less than 1°. In addition, no slump deposits, or beds deformed by slump have been recognized in the sediment associated with the Kenwood. For these two reasons, oversteepening is believed to have been a possible but not likely triggering mechanism for the Kenwood turbidites.

Seismic shock as the triggering mechanism for turbidity currents has the greatest amount of supportive evidence of any of the mechanisms discussed. That this is so is largely because of the precise times available for the occurrence of earthquakes, as well as the precise times known for subsea cable breaks from which rates of flow

TABLE 11

TRIGGERING MECHANISMS

Generative mechanism	Characteristic					
	Intensity		Interval			Number
	Variable	Uniform	Cyclic	Episodic	Years	
Storm surges		X	X		1-100	10-100
Floods		X	X		1-100	50-100
Hyperpycnal flow		X	X		1-100	50-100
Oversteepening	X		X	X	10-100	50-100
Seismic shock	X			X	10-1000	2-1000
Kenwood	X			X	1-1000	50±

have been determined for the turbidity current (Heezen and Ewing, 1952). Seismic shocks are of varying intensity and occur after successively varying intervals of time. Their occurrence is termed episodic rather than cyclic or periodic. Judging from moderately active seismic areas today, severe shocks in a non-trench environment may occur at intervals ranging from tens to thousands of years. Their number, too, is highly variable in a given locality, but they tend to be fewer on the so-called stable craton. Their frequency and magnitude are sufficient to warrant their consideration as likely mechanism for triggering turbidity currents that would result in beds similar to those of the proposed thin subsea fan model.

The turbidites of the Kenwood appear to have originated by triggering mechanisms of a wide range of intensity, in that the beds range in thickness from less than 0.1 foot to 20 feet. Similar ranges in the thickness of the shaly interbeds indicate intervals between generative incidents to range from a few years to several thousand years, assuming a sedimentation rate averaging 30 cm/1000 years on the basis of recent measurements discussed on p. 144. Of the mechanisms discussed above, seismic shock seems most in accord with the evidence from the Kenwood turbidites. (See table 11).

Facies analysis and the vertical profile

Before a complete paleogeography can be deduced for the subsea fan that embodies the Kenwood turbidites, a further analysis is is required. The entire Borden sequence as well as the underlying and overlying units must be interpreted in terms of their respective depositional environments. This interpretation is facilitated by application of Walther's Law (Walther, 1894, as outlined in Krumbein and Sloss, 1963, p. 318), through a facies analysis of the rock sequence, beginning with the oldest.

An increasing number of modern sedimentologic studies have concentrated on means of correlating the morphologic subdivisions of various depositional environments, such as deltas, with the character of the sediment and fauna in each subdivision. With subsurface information from within the depositional body, the studies further relate the morphologic subdivisions with discrete sedimentary facies. The term "facies" is used here to designate the lithologic and paleontologic aspect or appearance of each unit.

Several of the early stratigraphic studies in the Lower Mississippian and Upper Devonian rocks of the region placed great importance on the recognition of sedimentary facies within the complex sequence of terrigenous clastic rocks (Caster, 1934; Klepser, 1937; Stockdale, 1939). The facies concept of Caster (1934), has been applied directly to the Borden sequence by Stockdale (1939), not so much to define the depositional environment as to bring a semblance of stratigraphic order to the sequence. Klepser (1937) had applied the concept in his earlier study of the Mississippian rocks of Tennessee. Because the concept has been applied directly to the rocks included in the present study, a review of the concept is in order. Modifications are suggested to enhance the usefulness of the concept under the present philosophy of litho-versus chrono-stratigraphy.

Both Klepser (1937) and Stockdale (1939) found the facies concept well-suited to the clarification of time-stratigraphic (chronostratigraphic) relations of the Lower Mississippian sedimentary sequence in Indiana, Ohio, Tennessee and Kentucky. Because of the dominance of time-governed formational boundaries than extant, variations in lithology made necessary the designation of numerous facies within major formations (fig. 38). Parvafacies commonly are members within stratigraphic units, although the boundaries of parvafacies define both time and lithologic change. In the chronostratigraphic sense, however, one formation conceivably could be and commonly was lithogically identical to the overlying and underlying formations, which together constituted a magnafacies. The important stratigraphic concepts of this model deserve consideration despite the lack of general adoption of the terminology (Moore, 1949).

The approach of this study to the magnafacies-parvafacies model of Caster (1934, p. 20) is to follow the facies plane as the formational contact and to equate the magnafacies to a formation (fig. 38B). In a regressive sequence, the actualistic geometry of the planes of contemporaneity are inclined, whereas the facies planes parallel the base of the diagram (fig. 38C). In practice, of course,

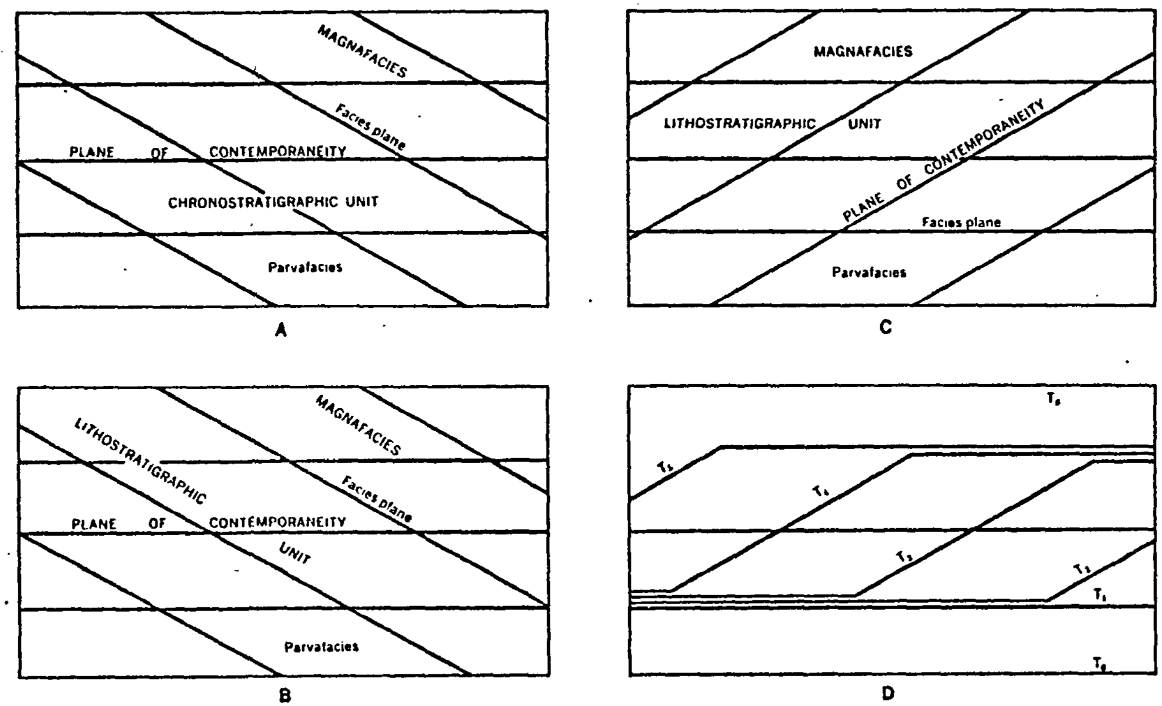


Figure 38. The facies concept (after Caster, 1934, p. 20). A. Applied to chronostratigraphic units; B. Applied to lithostratigraphic units; C. Lithostratigraphic orientation to better portray geometry of Borden Formation; D. Reoriented lithostratigraphic application modified to show effects of regressive sequence. T_n = successive planes of contemporaneity.

regressive sequences, lacunae, or erosional unconformities will cause the planes to coincide locally fig. 38D). Recognition of similar relationships in the sedimentary record has been pointed out for a Cretaceous sequence in Wyoming by Asquith (1970, fig. 34), and in the Miocene sediments of the Gulf Coast by Curtis (1970, fig. 2).

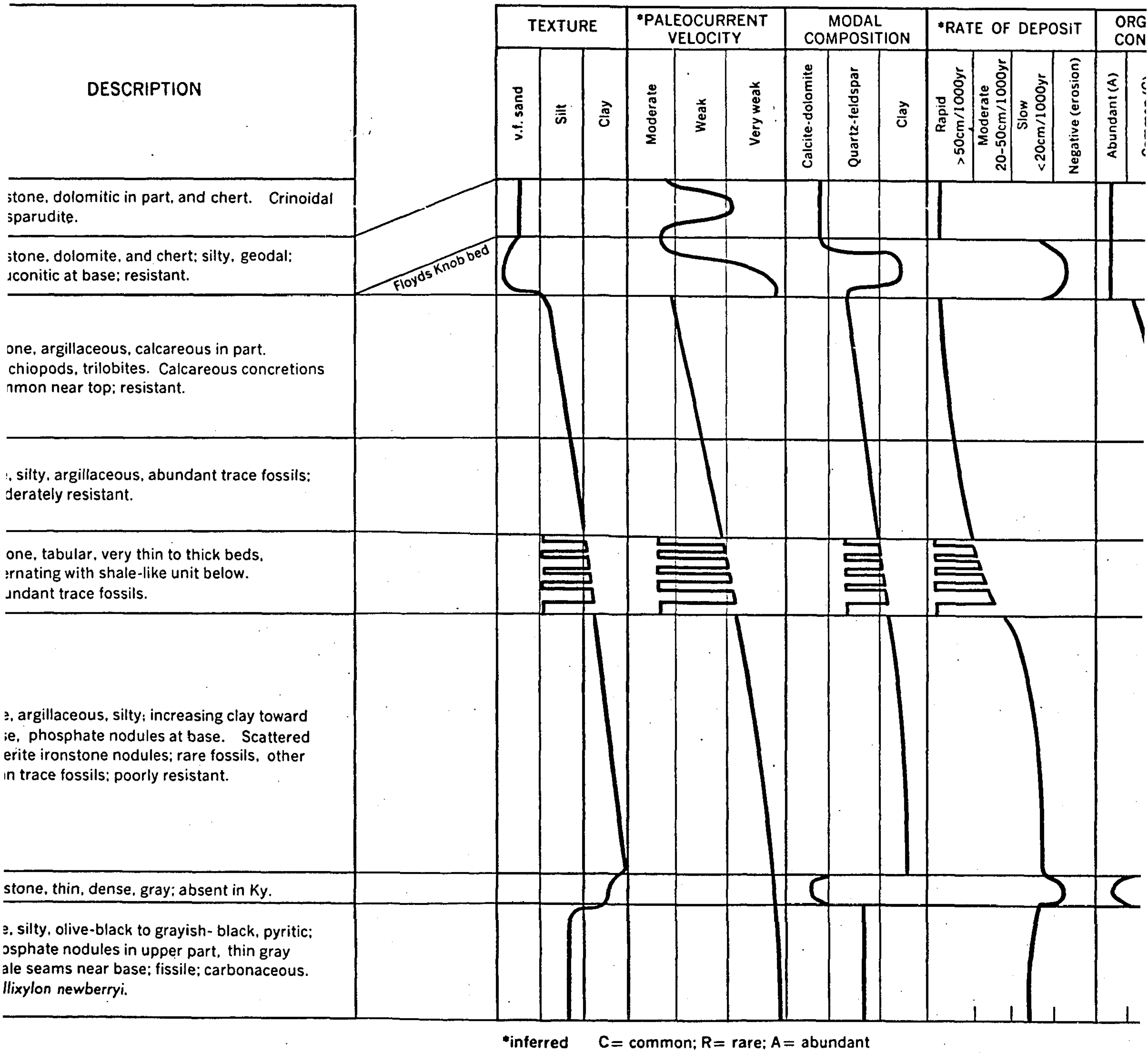
Information necessary to recognize sedimentary sequences in a vertical profile has been described by Visher (1965) as three types: (1) physical sedimentary aspects in terms of bedding, grain size, sorting, and sedimentary structures; (2) biologic aspects in terms of paleocology; and (3) presence and significance of sedimentary breaks. For the sake of interpretation, the entire Borden Formation as well as the underlying New Albany Shale and the overlying Harrodsburg Limestone are considered for the study area. The columnar section of this sequence of rocks, plus the vertical profile in terms of the three types of information listed above is shown in figure 39. Also shown is my interpretation of the environmental significance of this information relative to the vertical profile.

Environments of deposition

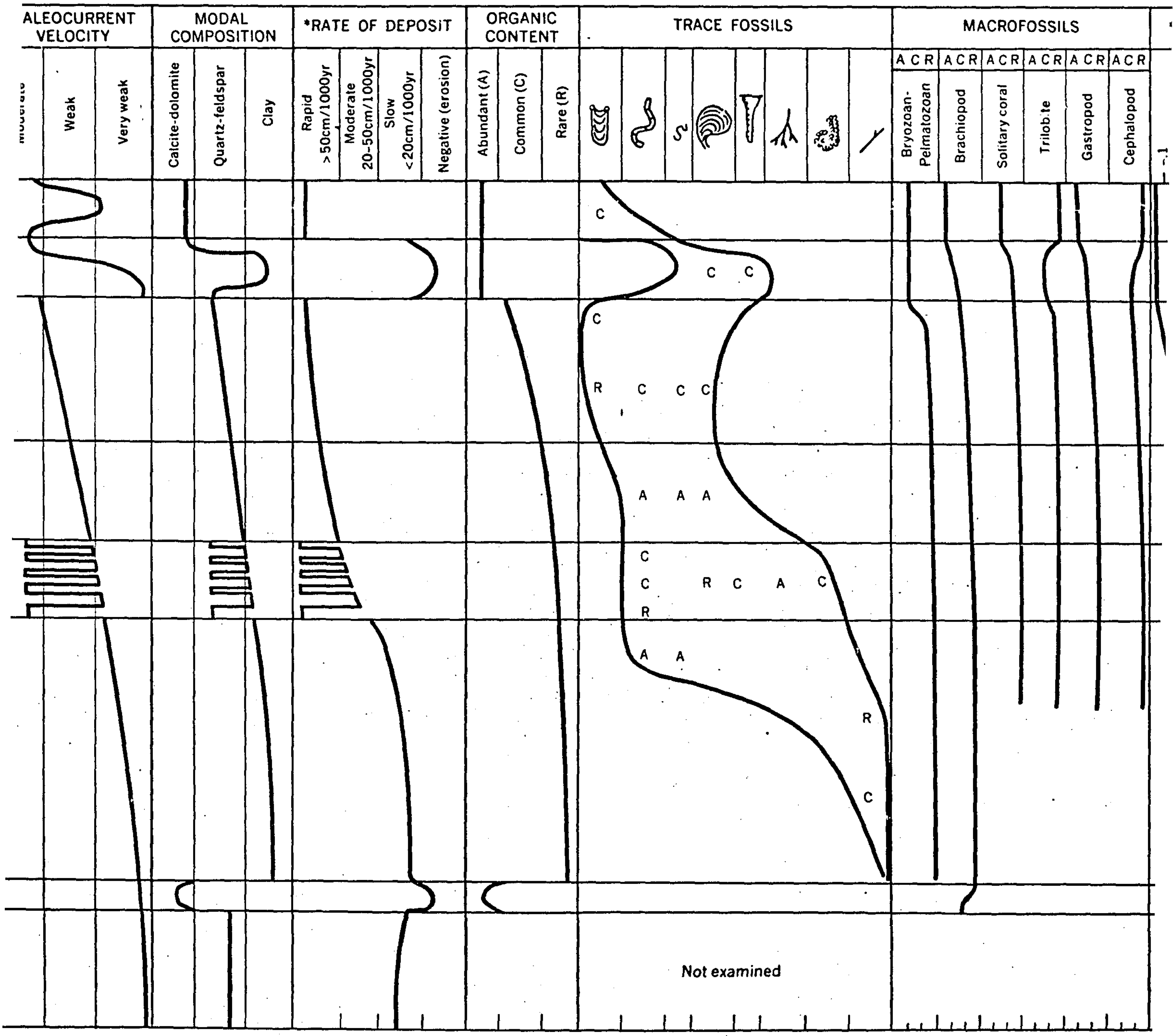
The depositional environments of the Borden can be characterized morphologically in order of decreasing depth of water as (1) basin-floor, (2) base-of-slope, (3) slope, and (4) platform. The first two of these environments have been called by Rich (1951a) fondoform, the other two clinoform, and undaform, respectively. As a group, these environments have been assigned depositionally to a deltaic environ-

SYSTEM	Series	FORMATION AND MEMBER		LITHOLOGY AND THICKNESS (in feet)	DESCRIPTION
MISSISSIPPIAN	Lower Mississippian	Harrodsburg Limestone		25-42	Limestone, dolomitic in part, and chert. Crinoidal biosparudite.
		Borden Formation	Muldraugh Member; Floyds Knob bed	20-60	Limestone, dolomite, and chert; silty, geodal; glauconitic at base; resistant.
			Holtsclaw Siltstone Member	0-133	Siltstone, argillaceous, calcareous in part. Brachiopods, trilobites. Calcareous concretions common near top; resistant.
			Nancy Member	20-130	Shale, silty, argillaceous, abundant trace fossils; moderately resistant.
			Kenwood Siltstone Member	0-85	Siltstone, tabular, very thin to thick beds, alternating with shale-like unit below. Abundant trace fossils.
			New Providence Shale Member	90-220	Shale, argillaceous, silty; increasing clay toward base, phosphate nodules at base. Scattered siderite ironstone nodules; rare fossils, other than trace fossils; poorly resistant.
		Rockford Limestone		0-3	Limestone, thin, dense, gray; absent in Ky.
DEVONIAN	Middle and Upper Devonian	New Albany Shale		65-130	Shale, silty, olive-black to grayish- black, pyritic; phosphate nodules in upper part, thin gray shale seams near base; fissile; carbonaceous. *Callixylon newberryi.*

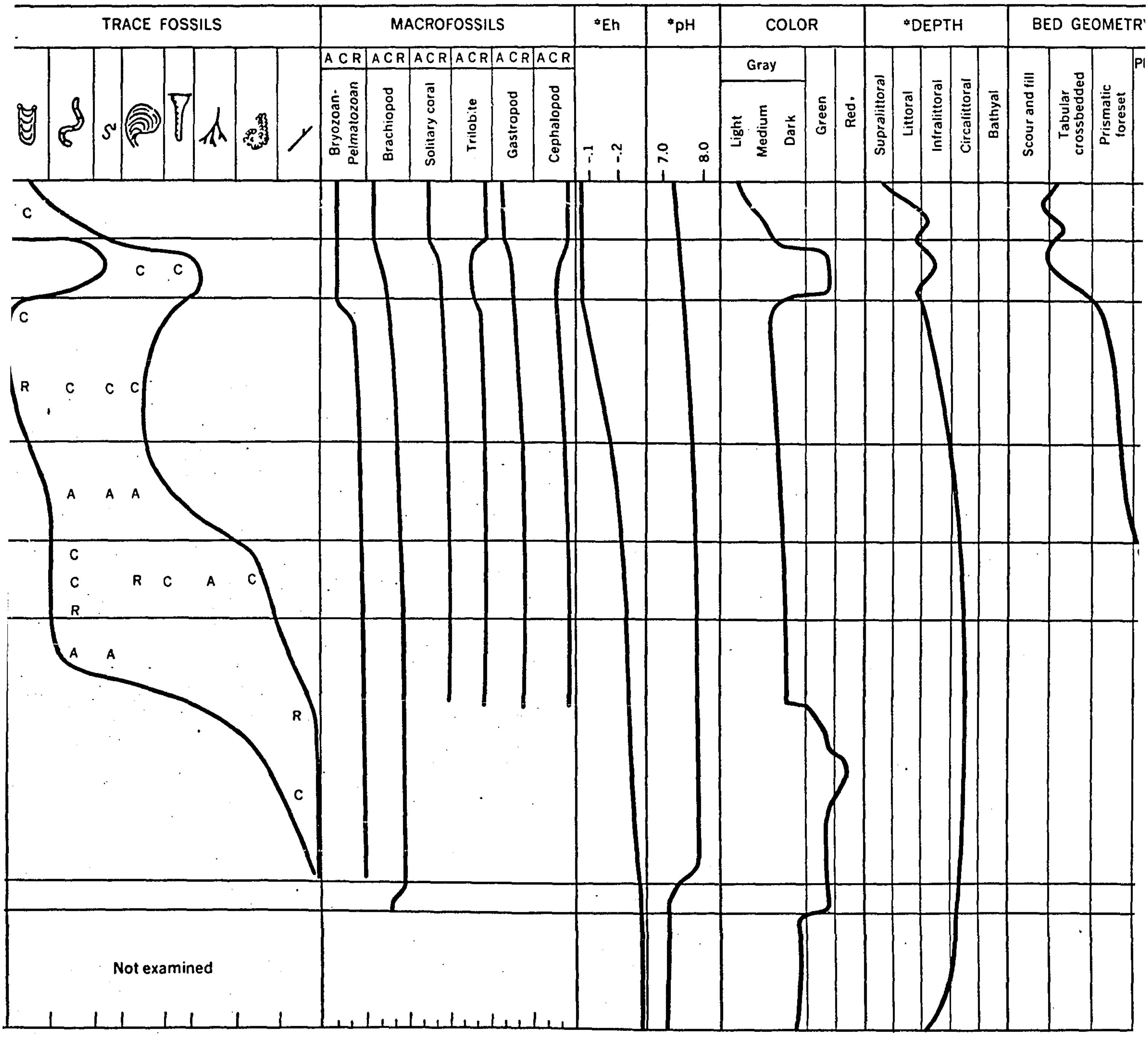
Figure 39. Facies analysis and vertical profile of the Borden Formation, north-central Kentucky.

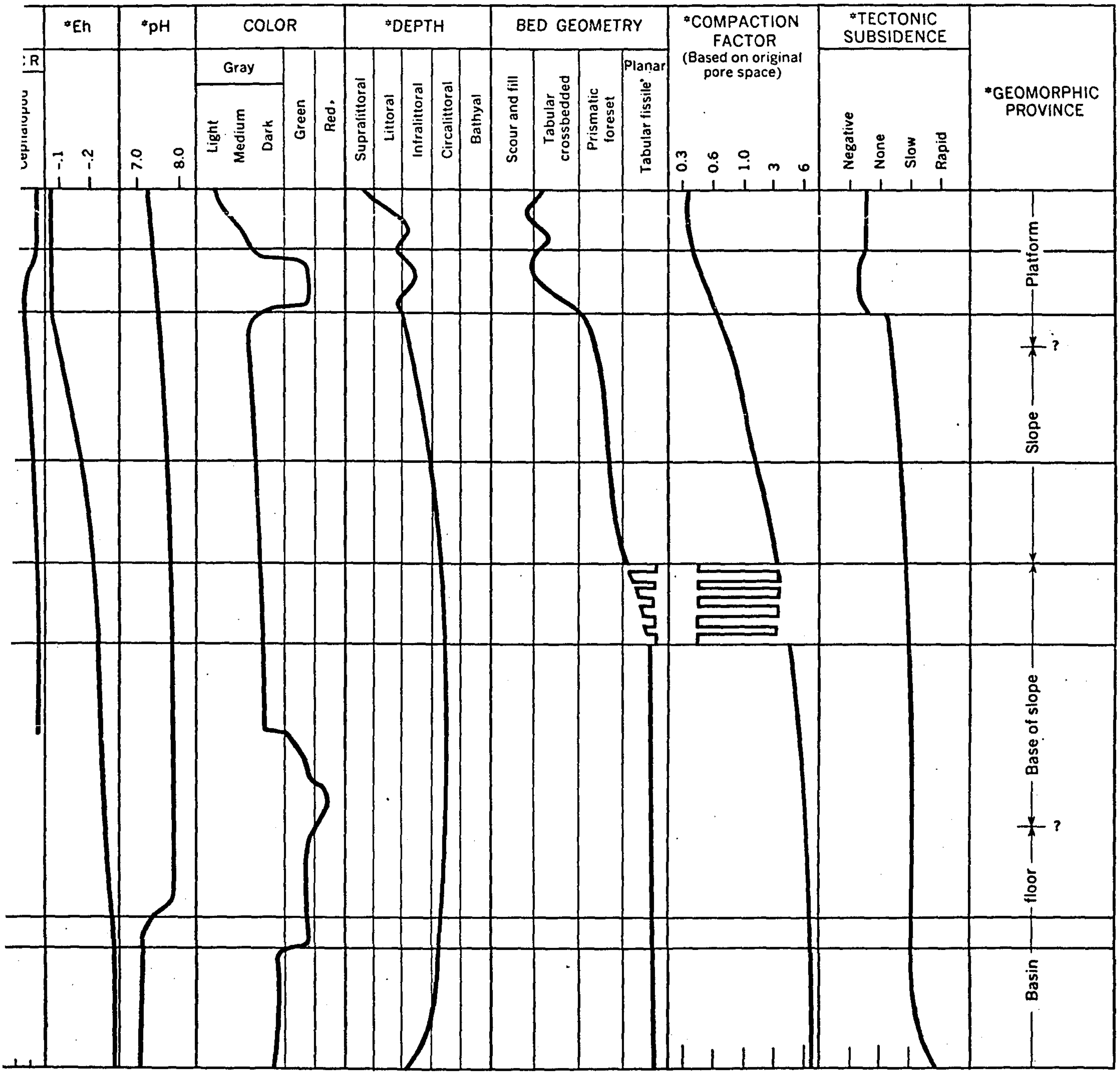


rofile of the Borden
cky.



:ommon; R= rare; A= abundant


TRACE FOSSILS
MACROFOSSILS
*Eh
*pH
COLOR
*DEPTH
BED GEOMETRY
A C R
Bryozoan-Pelmatozoan
Brachiopod
Solitary coral
Trilobite
Gastropod
Cephalopod
-.1
-.2
7.0
8.0
Gray
Light
Medium
Dark
Green
Red
Supralittoral
Littoral
Infralittoral
Circalittoral
Bathyal
Scour and fill
Tabular crossbedded
Prismatic foreset
Not examined


*Eh
*pH
COLOR
*DEPTH
BED GEOMETRY
*COMPACTION FACTOR
(Based on original pore space)
*TECTONIC SUBSIDENCE
*GEOMORPHIC PROVINCE
Gray
Light
Medium
Dark
Green
Red
Supralittoral
Littoral
Infralittoral
Circalittoral
Bathyal
Scour and fill
Tabular crossbedded
Prismatic foreset
Planar
Tabular fissile
-.1
-.2
7.0
8.0
0.3
0.6
1.0
3
6
Negative
None
Slow
Rapid
Platform
Slope
Base of slope
floor
Basin
?

ment (Rich, 1951a; Swann and others, 1965; Peterson and Kepferle, 1970). The term "delta" has been spurned by Sloss (1962, p. 1055), who prefers to use "clastic wedge", and by Walker and Harms (1971) and Walker (1971), who suggest that sediments in similar morphologic position accumulated in a prograding shore marginal (paralic) environment. Perhaps, however, the distinction between the term delta and these other terms in ancient rocks is artificial. The expanded definition of the term delta as proposed by Moore and Asquith (1971, p. 2566), seems to eliminate some of these disagreements: "The subaerial and submerged contiguous sediment mass deposited in a body of water (ocean or lake) primarily by the action of a river."

A deltaic sequence is well suited to facies analysis. The sedimentary facies and breaks in sedimentation involved in the vertical profile study of the Borden are listed with the anticipation that an environment of deposition can be proposed for each. A black shale facies is represented by the pre-Borden, New Albany Shale. The first of two hiatuses in sedimentation is represented by the zone of phosphate nodules at the base of the Mississippian sequence. Four terrigenous lithologic facies are recognizable in the clastic portion of the Borden, above which the second major break in sedimentation is identified by a bored, glauconitic surface, followed in turn by two carbonate rock facies, both of which are treated herein somewhat superficially.

The black shale facies and the four terrigenous lithologic facies represent the four geomorphic associations mentioned above:

basin floor, base-of-slope, slope, and platform (the latter modified from Wilson, 1969, p. 18). The carbonate facies represent variations of the carbonate platform. The details of these environments are examined below and are summarized in figures 39 and 40.

Basin-floor environment

The black shale facies typefies the early phase of the basin-floor environment. Because of the wide area it covers, it forms the base for the ensuing greenish gray shale and siltstone which encroached over it from the east during Early Mississippian time. As a precursor to the Borden, the depth, geochemistry, texture, and rate of accumulation of the black shale affords a basis of comparison with the overlying green-shale facies of the Borden. In general, those workers who have studied the black shale environment agree on all characteristics except the depth. The environment is mainly anaerobic, implying poor circulation; this assessment is supported by the clay- to silt-size of the constituent particles, and by the slow rate at which it apparently accumulated. Conant and Swanson (1961, p. 54-55) suggest an accumulation rate of about 5 cm/1000 years.

Two thin zones of gray shale within the black shale have been attributed to periods of aeration (Lineback, 1968b, p. 1303; Conant and Swanson, 1961, p. 56). Because these zones are not cyclic and are widespread, a possible explanation is that a widespread volcanic ashfall effectively destroyed any organic flotant (as postulated by

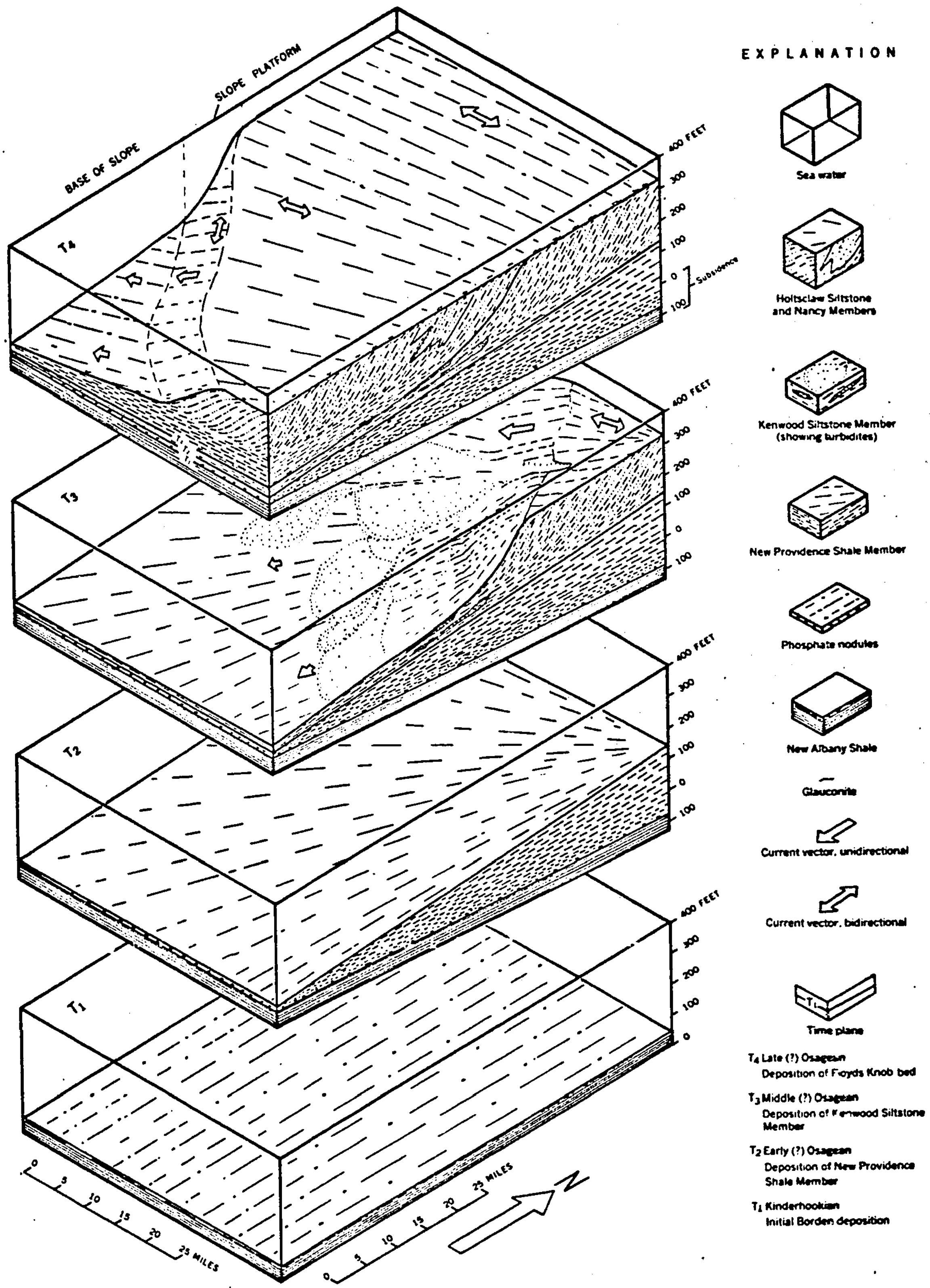


Figure 40. Sequential block diagrams showing depositional environments of the Borden Formation.

Lineback, 1968b), and initiated aerating density currents. This hypothesis remains to be tested.

If the depth of water in which the black shale facies accumulated were known, it could furnish a strong basis for interpreting the environment of deposition of the overlying Mississippian green shales. A wide range of depths have been suggested for the origin of the Devonian black shale of North America of which the New Albany Shale is a part. Earlier workers suggest that the euxinic environment in which these black shales accumulated may have been in deep water (Lapworth, 1889, p. 60; Clarke, 1904, p. 199-201; Rich, 1951b, p. 2038-2039), shallow water (Grabau and O'Connell, 1917; Kiepser, 1937; Stockdale, 1939, p. 38; Pepper and others, 1954, p. 97; Conant and Swanson, 1961, p. 60-62), or of varying depths (Ulrich, 1911, p. 356-361; Twenhofel, 1939, p. 1196-1197; Lineback, 1968b, p. 1303). A recent paper by James (1971) indicates that deeper water may be more prevalent than shallow, proposing that the anoxic water system results from the development of a widespread density gradient which inhibits circulation of bottom water. This, however, does not solve the enigma of depth, but merely emphasizes it. The absolute depth of the basin in which the black shale was deposited remains unknown. From an upward decrease in gray shale interbeds, and from a widespread basal thin sand interpreted as a transgressive sheet sand, however, it is preferable to think of the black shale as having been deposited in an environment of gradually increasing depth, possibly ranging from circalittoral to infralittoral.

The thin zone of phosphate nodules overlying the black shale in the study area and included in the basal New Providence Shale Member is believed to represent a depositional lacuna. The zone is equivalent to the Falling Run Bed of the New Albany Shale as defined by Lineback (1968b), and to the Maury Shale of Tennessee (Conant and Swanson, 1961). These workers have attributed the entire Kinder-hookian interval to this phosphatic zone and the several inches of green shale and discontinuous limestone above it (Lineback, 1968b, fig. 7; Conant and Swanson, 1961, p. 67). From this, deposition on the basin floor appears to have been minimal in earliest Mississippian time, and the zone of phosphate nodules on the black shale appears to be a synchronous surface. The regularity and continuity of this zone indicates that the surface was not swept by strong currents.

Deposition on the basin floor resumed in a somewhat more aerated environment. Predominantly green clayey sediment prevailing through-out most of the study area indicates pelagic deposition from a distal terrigenous source. That this source was to the east is indicated in the study area by a thickening of the clayey sediments in an easterly direction (Peterson and Kepferle, 1970, fig. 4C).

The characteristics of the basin-floor environment following the accumulation of the phosphate nodules are:

1. Beds essentially flat-lying; surface slopes slightly to the west less than 10 feet per mile.
2. No significant bottom current.

3. Epifauna and infauna sparse.

4. Low oxygenation. Local siderite, glauconite, and phosphate indicative of Eh from 0 to -.25, pH from 7.0 to 7.8$\pm$ (Krumbein and Garrels, 1952, fig. 8).

5. Widespread muddy bottom from pelagic sediment.

6. Depth greater than 250 feet. (See discussion of slope environment, p. 142-147).

Base-of-slope environment

The upper silty clay shale of the New Providence, the flat-lying tabular siltstones, and channel-fill siltstone of the Kenwood were sediments deposited on an essentially flat basin floor at the base of a slope leading upward to a prograding deltaic or paralic platform. The shale of the New Providence becomes increasingly silty, changes from green to gray, and contains increasingly abundant trace fossils upwards. These fossils are mainly of the small boring types, with possible stick-like plant remains less than 1 mm thick more common near the base of the sequence. Because deposition was somewhat more rapid near the base of the slope, dip of the slope was probably somewhat steeper than on the basin floor. From these generalities and from details discussed earlier in the paper concerning the New Providence and the Kenwood, the characteristics for the base-of-slope environment are:

1. Beds essentially flat-lying; surface slopes to the west at 10 to 25 feet per mile.

2. Relatively low-energy gravity-driven density currents from a slope that faced essentially west; currents were episodic, debouching from at least two incipient canyons.
3. Benthonic infauna expressed as trace fossils relatively abundant.
4. Low oxygenation; Eh from 0 to -.25; pH from 7.0 to 7.8±, similar to that from basin-floor environment.
5. Bottom muddy with increasing amount of silt.
6. Depth shallows from the basin floor by ±100 feet.

Slope environment

The rocks above the predominantly clay shales of the New Providence originated in the slope environment. The siltstone and silty shale of this environment constitute the Nancy and Holtsclaw Siltstone Members. These units show obscurely ripple-laminated bedding that is disturbed by biogenic reworking (bioturbation) in increasing amounts upwards. Scattered invertebrate remains also become increasingly abundant upwards in the rock sequence and include brachiopods, bryozoa, gastropods, trilobites, and scattered banks of crinoidal limestone. In the sediments immediately overlying the Kenwood, fall-off to the west is indicated in the coarser and more resistant massive siltstone of the Holtsclaw (Kepferle, 1971, 1972a, b).

Major evidence for the presence and magnitude of the slope environment is furnished in the study area by the relief of the contact between the Muldraugh Member and the underlying units of the Borden Formation along the Borden delta front (Peterson and Kepferle, 1970, fig. 4B), less than 10 miles west of the Kenwood. This contact is marked in Kentucky by the Floyds Knob bed, a bored surface and glauconitic deposit, which is assumed to represent another lacuna. As such it delineates the topography of the sea floor at the time progradation of the delta front ceased and inference represents the typical topography during the deposition of the clastic units.

Correlation of the New Providence, Nancy, and Holtsclaw members eastward beneath this contact at the base of the Muldraugh from the Borden delta front to the portion of the Borden underlain by the Kenwood indicates that no marked lithologic changes take place in this interval, indicating that no differences in depositional environment occur between the front and the area of Kenwood deposition. Hence, the slopes down which the turbidity currents flowed to introduce the Kenwood siltstone to the base-of-slope environment were approximately the same magnitude as the front marked by the glauconitic contact. The local relief on this front is 200 feet in a distance of from 4 to 8 miles; the rate of slope is from 25 to 50 feet per mile over the entire distance, although locally it is as much as 120 feet per mile--slightly more than 1 degree (Peterson and Kepferle, 1970, fig. 4B). Similar slopes are common on modern deltas (Fisk, 1961; Mathews and Shepard, 1962; Allen, 1970; Curray, 1969).

In considering how nearly this relief approaches the original relief on the depositional front, major concerns are (1) the effects of compaction, (2) post depositional truncation of the sedimentary sequence, and (3) post-depositional tectonic deformation. No direct evidence of truncation or deformation has been found in the study area. Compaction, however, deserves consideration.

Based on studies off the Fraser River delta, Mathews and Shepard (1962) indicated that muds tend to undergo compaction with a loss of 50 percent of their original volume, and that most of this takes place within 2000 years of deposition. Assuming that the rate of sediment accumulation ranges from 5 to 180 cm/100 years (Emery and Bray, 1962, p. 1839) or on major deltaic cones, where accumulation ranges from 10 to 30 cm/1000 years (Ewing and others, 1958; Huang and Goodell, 1970; Stanley and Huang, 1971), 30 cm/1000 years is an average rate of accumulation for the Borden clastics. Following this reasoning, then only the top meter of sediment would be relatively uncompacted in the Borden. The remaining post-depositional compaction would be small and would have little effect on the overall relief of the front. In other words, the slope preserved in the geologic record is essentially the same as the slope that was present during the deposition of the Kenwood. This would also account for the firmness of the substrate as reflected in the sharp features preserved as sole markings on the base of the Kenwood siltstone beds.

Studies by Athy (1930, in Pettijohn, 1957, p. 354) indicate that burial beneath 1000 feet of sediment may cause a further loss of volume by 20 percent in addition to the loss from initial compaction. If such a figure is based on the total uncompacted thickness, and if the thickness of sediment remaining is 120 feet, the total thickness lost by deep burial is 80 feet. This post-burial compaction is applicable mainly to clays rather than to silt and sand. The effects of compaction of Borden sediment by deep burial would be mainly to reduce the apparent slope of the post-burial front from that of the pre-burial front, because clay makes up most of the basal third of the Borden, silt makes up the upper third, and the middle third is a mixture of the two. Calculations indicate that the amount of this reduction is likely less than 10 feet per mile, and the relief on the front, which now measures as 200 feet across a distance of from 4 to 8 miles (Peterson and Kepferle, 1970, fig. 4) may have been as great as 280 feet, with an average slope of from 35 to 70 feet per mile. This range is comparable to the slope found on modern deltas.

If, on the other hand, the sedimentation rate on the slope environment were more rapid than that on the base-of-slope environment, the effects of initial porosity and syndepositional compaction would be increased so that, although the overall relief remained the same, the final inclination of the strata would be steeper than the slope on which the sediment was deposited. This is not believed to have had notable effect on the dip of the sequence directly over the Kenwood.

Effects and extent of possible post-depositional truncation preceding the lacuna represented by the bored glauconitic surface are more difficult to assess. In a normal regressive sequence, the prograding slope or delta-front environment is overlain by the delta marginal bar sands (Fisk, 1961), barrier island, or chenier plain sands (Curray, 1969). Nowhere in the study area do the Borden sediments as coarse as very fine grained sand occur below the glauconitic zone. The absence of very fine grained sandstone in the turbidites of the base-of-slope environment indicates that little or no sand was present on the original slope. Inasmuch as the coarsest grains in the base-of-slope siltstones are similar to those in the upper part of the slope facies, erosional truncation of the terrigenous clastic sequence in the study area is judged negligible. The likelihood that no nearshore environment reached as far west as central Kentucky during the regression supported by the fact that the distal edge of the terrigenous clastic wedge reached only slightly beyond the west edge of the study area. No justification, therefore, can be found for extending the estimate for the maximum relief of the front in the study area for more than 280 feet.

The characteristics of the slope environment are:

1. Surface slopes range from 25 feet per mile to more than 1° (90 feet per mile) over a distance of about 4 to 8 miles.
2. Local incipient canyons carry turbidity currents of moderate energy; upper part of slope swept by low energy surface-generated currents.

3. Epifauna and infauna increase in abundance upwards.
4. Somewhat higher oxygenation than at base of slope; Eh from 0 to -.25, pH from 7.5 to 8.5$^{\pm}$.
5. Widespread muddy substrate, increasingly silty near top.
6. Depth of water infralittoral (below tidal zone to 150 feet) to circalittoral (150 to 600 feet, Krumbein and Sloss, 1963, p. 259).

Platform environment

No sediment accumulated on the platform except perhaps the uppermost few feet of the Holtsclaw Siltstone, or, where the Holtsclaw is absent, the Nancy Member. The sediment of these few feet is mainly represented by siltstone or clayey silt shale containing abundant brachiopods, bryozoa, gastropods, trilobites, and scattered banks of crinoidal limestone and trace fossils. Original ripple lamination is obscured by bioturbation. Trace fossils are more abundant in the clayey shale. Most of the platform may have been swept by surface storm and tidal currents. As subsidence was not great, most of the deposition took place at the edge of the platform on the slope environment.

The characteristics of the platform environment are:

1. Beds essentially flat; surface slopes to the west only slightly if at all.
2. Surface currents from waves and tides moderate to low energy.

3. Epifauna relatively abundant.
4. Eh -.1 to -0.2, pH 7.8±; lack of limestone-producing organisms attributed to turbid water.
5. Bottom mainly silty mud.
6. Depth below tide level in upper infralittoral zone (24 to 60 feet) corresponds to similar zone off Niger delta (Allen, 1970, p. 143).

Erosional phase and depositional lacuna

This interval is commonly represented by the Floyds Knob bed. The zone is persistent, is as much as 15 feet thick, and contains at least one and in many places two layers in which glauconite is concentrated. Oolitic limestone with local thin beds showing bimodal cross-bedding indicate a shoaling environment of deposition within the tidal zone. Limestone is not widespread in this zone in Kentucky; instead, the zone is commonly represented by glauconitic silt and sand. Glauconite-filled burrows in the surface of the underlying slope deposits indicate a considerable lacuna in sedimentation on this surface. The lacuna may correspond to the destructive phase in deltaic deposition (Scruton, 1960). Scruton (1960) explains the destructive phase as caused by a shift in the dispersal pattern of the terrigenous clastics, followed by continuing compaction and resulting in marine transgression over the sediment moss. Such a destructive transgression readily explains the effective removal of remnants of Floyds Knob limestone and the terrigenous platform facies from the sedimentary record in much of central Kentucky.

Carbonate platform environment

An infralittoral origin for the sediment of the Muldraugh Member of the Borden is indicated by a preponderance of calcite and dolomite in silt-sized grains, by the abundance of anhydrite and gypsum as precursors of quartz geodes (Chowns and Elkins, 1971), and by the bryozoan-crinoid-brachiopod invertebrate fauna. The increase in locally derived carbonate in the Muldraugh is marked by a corresponding decrease in the amount of terrigenous detritus reaching this part of the sedimentary platform. Sedimentary fall-off to the southwest in some of the associated limestone and sandstone bodies (Sedimentation Seminar, 1972), indicate that this infralittoral environment was swept intermittently by westward-flowing currents sufficiently strong to winnow crinoidal meadows and redeposit the debris as crinoidal banks on the platform edge. This thin carbonate platform appears to have prograded westward and eventually reached the edge of the terrigenous sediment platform on which deposition had essentially ceased. Details of the carbonate platform environment remain to be worked out by further study.

The paleoslope and paleotectonics

Evidence for a west-southwest paleoslope during the deposition of the Kenwood comes from four factors:

1. The southwest stratigraphic descent of the Kenwood Siltstone

Member within the Borden.

2. The southwest imbrication of the individual siltstone beds in the Kenwood.
3. The west-southwest direction of sole markings and other paleocurrent indicators within the Kenwood Siltstone beds, particularly the turbidites, which in themselves indicate deposition from down-slope gravity currents.
4. The west-southwest slope of the Borden delta front, as revealed by the configuration of the Floyds Knob bed and extrapolated for Kenwood-time by application of Walther's Law.

The fourth factor, combined with the proximal thickening of the siltstone beds to the east and northeast, indicates that the paleo-slope was present at the initiation of the deposition of the Kenwood beds. The persistence of the slope in the sediment beyond the extent of the Kenwood, both to the east and to the west indicates that neither the presence of the slope alone nor ordinary accretional progradation was sufficient to initiate turbidity currents. Rather, these relationships suggest that the turbidites were triggered by a somewhat unique and episodic mechanism such as seismic shock.

Orientation and migration of the paleoslope

The strike of the paleoslope during the deposition of the Kenwood paralleled closely the orientation of the depositional strike of the Kenwood. By the end of terrigenous clastic deposition in the Borden of this area, the strike of the paleoslope swung slightly west of this (fig. 6). A comparison of the paleocurrents for the Kenwood with those of the Farmers Siltstone Member of the Borden in northeastern Kentucky indicates that the paleocurrent system was essentially constant (fig. 41). In a regional paleographic reconstruction of Early Mississippian (Kinderhookian) time, Pepper, de Witt, and Demarest (1954, pl. 13) infer the presence of an island, penninsula, or shoals, called Cincinnatia, over the axis of the present Cincinnati arch. Because the paleocurrents of the Kenwood show no evidence of deflection from the pattern established by the earlier deposits of the Farmers Siltstone, and because the immaturity and modal mineral analysis of the arkose siltstones of the Kenwood and the Farmers differ so slightly, a current-deflecting deep-weathering lowland such as that postulated as Cincinnatia could not have been emergent during deposition of these siltstone bodies.

Sedimentation rates and lithologies remained fiarly consistent through this interval of Early Mississippian time and the strike of the paleoslope was nearly linear for more than 60 miles. Comparable persistence of strike and linearity of paleoslope for more than 100 miles has been demonstrated for Middle and Upper Devonian rocks in the Appalachian Basin (Frakes, 1967, p. 107). Regional paleocurrents for Early Mississippian time are compared on figure 42 .

Paleotectonics

The paleotectonic implications of this westward persistance of

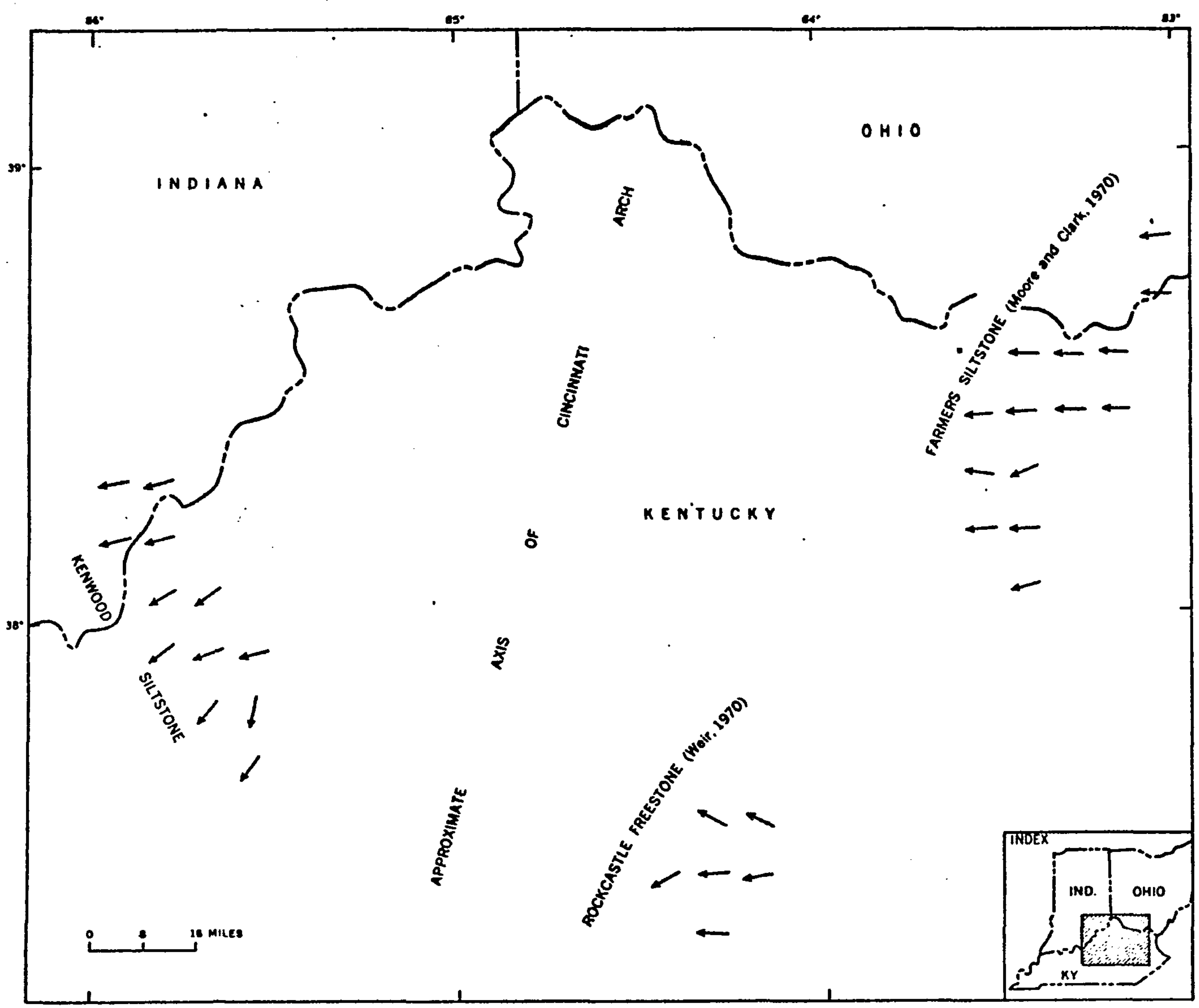


Figure 41. Paleocurrents in the Borden Formation in Kentucky.

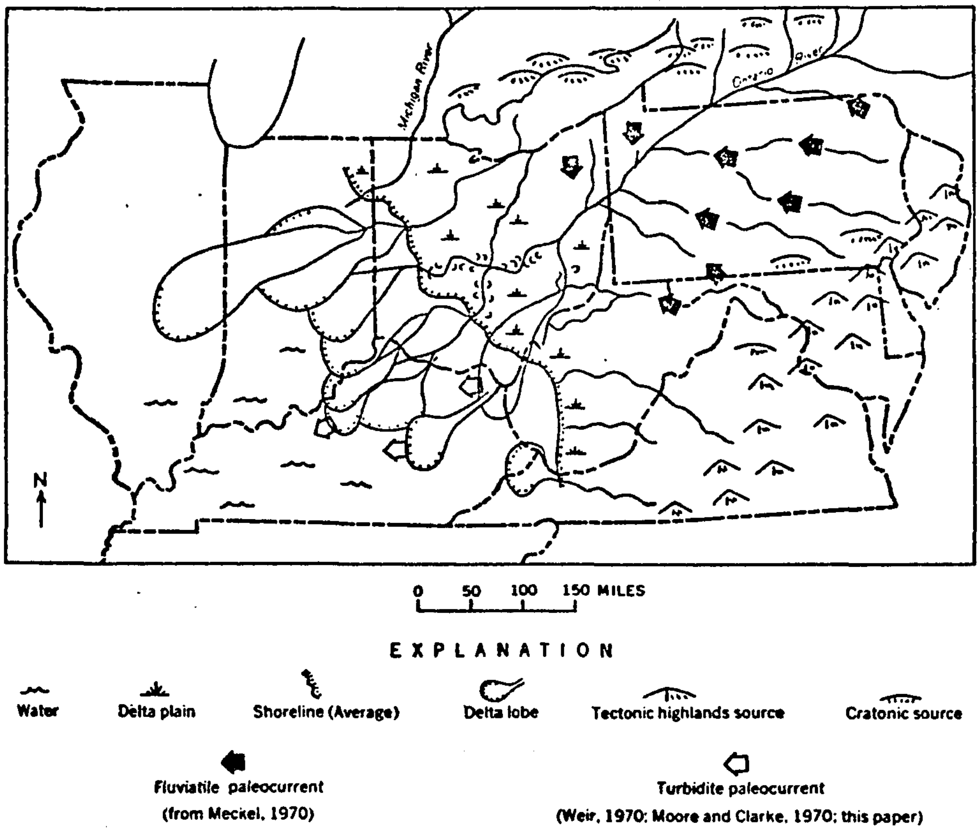


Figure 42. Paleogeographic diagram of eastern interior during deposition of Kenwood Siltstone Member and related Lower Mississippian rocks prior to final establishment of Borden delta front.

paleoslope indicates that the orientation and magnitude of the tectonic setting of the Eastern Interior and Appalachian basins in Late Devonian continued into Early Mississippian time. In the model for continental margin deformation furnished by Bird and Dewey (1970), the Acadian orogeny is attributed to continental plate collision. They also indicate (p. 1048) that the resulting "deformation is reflected in the westward migration of the Middle Devonian molasse, supplying a delta front-flysch facies in the Catskill Basin." The final stages of the Acadian orogeny in and east of New England fostered the maximum westward advance of the Pocono alluvial wedge (Meckel, 1970, p. 54). Using the correlation technique of Israelsky (1949) and allowing for the removal of much of the upper part of the Catskill delta complex by the ensuing destructive phase, the most distal advance of the deltaic sequence is represented in central Kentucky and southern Indiana by the wedge edge of clay- and silt-shale assigned herein to the basin floor, base-of-slope, and slope environments of the Borden delta. Dwindling paroxysms of minor strain release, perhaps far to the east, initiated slope failure and turbidity currents along the front of the active distributary channels of the major streams. Two such channels on the delta front in central Kentucky were the dispersal centers for the turbidites of the Kenwood Siltstone Member of the Borden. Subsidence of the shelf on which this deltaic sequence was prograding was probably more rapid in central Indiana than in central Kentucky, continuing the trend which had begun in the Middle

Devonian (fig. 13). Some of the differential may reflect continued positive--or rather--less negative influence of the Cincinnati arch, but not nearly so much as is reflected in the more than 200 feet of stratigraphic relief shown beneath the pre-middle-Devonian erosion surface between Jefferson County, Ky. (Kepferle, 1972b), where the Middle Devonian limestone lies on more than 190 feet of Silurian rocks, and central Kentucky (Kepferle, 1972c, in preparation), where the upper 50 feet of the Ordovician section is missing beneath this unconformity. Indications that the Cincinnati arch was emergent or even shoaling in Kentucky during Late Devonian or Early Mississippian, however, are lacking.

Persistent evidence of westerly paleocurrents in this part of the eastern Interior basin abound. Western paleocurrents are found in the upper part of the Borden-Fort Payne sequence (Hrabar and others, 1971, and Sedimentation Seminar, in press), the Salem Limestone (Sedimentation Seminar, 1967, fig. 6), the Chester age rocks (Sedimentation Seminar, 1969, fig. 7; Potter and others, 1958, fig. 15), the Pennsylvanian sequence (Potter and Siever, 1956, fig. 4), the Cretaceous (Pryor, 1961, fig. 6), and the Tertiary (Potter and Pryor, 1961, table 7). All evidence indicates that the regional structural paleoslope has not changed, with the possible exception of slight local reversals, even into the Recent in this part of the eastern Interior basin.

This persistence of paleoslope is difficult to explain tectonically. The concept of load tectonics has been proposed by

McIver (1970, p. 80) as the crustal response to the deposition of sediment in deltaic sequences in comparison with crustal downwarps in flysch basins. This does not explain the persistence. One could as easily infer that deltaic depocenters are tectonically negative, thereby accounting for the geographic localization of continental drainage and deltaic deposition. The explanation that the "uneven balance between basin subsidence and deltaic progradation leads to complex intertonguing of facies" is applicable in either case, (McIver, 1970, p. 80).

The concept of the geosynclinal cycle as outlined by Pettijohn (1957, p. 637, after Krynine) also fails to explain the persistence of the paleoslope. It does, however, seem to explain the sedimentation pattern of the Upper Devonian and Lower Mississippian rocks in the Eastern Interior. Because the tectonic activity that produced the Kenwood turbidites was waning and represents the end of this stage of the tectonic cycle, the turbidite-generating capacity was also slight. This, in turn, gave little impetus to the formation of submarine canyons. Such canyons, if present, were embryonic and geologically short-lived, resulting in the incipient formation of subsea fans at their mouths along the base of slope of the prograding sequence of terrigenous clastics.

Perhaps, an explanation for the persistence of the paleoslope will be found in the intricacies of the New Global Tectonics.

CONCLUSIONS

The apparent complexity of the Borden Formation (Mississippian) in north-central Kentucky and southern Indiana is reduced by a study of the stratigraphic and lithologic details of the Kenwood Siltstone Member. The Kenwood is a mappable lithostratigraphic unit that also appears to be a time-stratigraphic unit, in that it is characterized by a sequence of turbidites that is thin, therefore short-lived.

Stratigraphy, bedding characteristics, and indicators of westward-trending paleocurrents all point to a thin subsea fan as a model for the immediate environment of deposition of the Kenwood. Trace fossils in the Kenwood belong to the Cruziana and Zoophycos assemblages (Seilacher, 1967, fig. 2). Depth ranges attributed to these fossil assemblages indicate the Kenwood probably accumulated in the circalittoral zone (150 to 600 feet).

Provenance studies using the paleocurrent data combined with compositional and textural characteristics of the Kenwood indicate an eastern source for the sediments analagous to those for the Farmers Siltstone Member. A vertical profile and facies analysis of the Borden, aided by the geometry of the Borden delta front as summarized by Peterson and Kepferle (1970), permits the recognition of the basin floor, base-of-slope, and slope environments represented in the pro-delta and delta-front lithologies of the Borden. A comparison with studies of Early Mississippian paleocurrents and paleotectonics of the Appalachian basin indicates that the terrigenous clastics of the

Borden constitute the distal marine edge of the westward-prograding terrigenous clastic wedge here called the Catskill-Pocono delta complex.

EPILOGUE

The Devonian mountains are gone,
and where they once rose in defiant heights
their very foundations
  are broken
    and buried,

But in the remnants
of formations born of destruction,
we may read the epitaph
  which records
    their greatness.

(Barrell, 1914, p. 253)

REFERENCES CITED

Allen, J. R. L., 1970, Sediments of the modern Niger delta: A summary and review, _in_ Morgan, J. P., and Shaver, R. H., eds., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 138-151.

Ambraseys, N. N., 1969, The seismic sea wave of July 9, 1956, in the Greek Archipelago: Jour. Geophys. Research, v. 65, p. 1257-1265.

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 645-665.

Asquith, D. O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1184-1224.

Barrell, J., 1913, 1914a, b, The Upper Devonian delta and the Appalachian geosyncline: Am. Jour. Sci., v. 36, p. 429-472; v. 37, p. 87-109, 225-253.

Bates, C. C., 1953, Rational theory of delta formation: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2119-2162.

Beall, A. O., Jr., 1970, Turbidites of the Gulf of Mexico abyssal plain: Geol. Soc. America Abs. with Programs, v. 2, p. 490.

Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geol. Soc. America Bull., v. 81, p. 1031-1060.

Bokman, John, 1957, Suggested use of bed-thickness measurements in stratigraphic descriptions: Jour. Sedimentary Petrology, v. 27, p. 333-335.

Bornhold, B. D., and Pilkey, O. H., 1971, Bioclastic turbidite sedimentation in Columbus Basin, Bahamas: Geol. Soc. America Bull., v. 82, p. 1341-1354.

Bouma, A. H., 1962, Sedimentology of some flysch deposits; a graphic approach to facies interpretation: Amsterdam, Elsevier, 168 p.

________ 1964, Notes on X-ray interpretation of marine sediments: Marine Geology, v. 2, p. 278-309.

Bouma, A. H., and Shepard, F. P., 1964, Large rectangular cores from submarine canyons and fan valleys: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 225-231.

Buffington, E. C., 1961, Experimental turbidity currents on the sea floor: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 1392-1400.

Butts, Charles, 1915, Geology and mineral resources of Jefferson County, Kentucky: Kentucky Geol. Survey, ser. 4, v. 3, pt. 2, 270 p.

________ 1922, The Mississippian series of eastern Kentucky: Kentucky Geol. Survey, ser. 6, v. 7, 188 p.

Caster, K. E., 1934, The stratigraphy and paleontology of northwestern Pennsylvania. Part I: Stratigraphy: Bulls. Am. Paleontology, v. 21, no. 71, 185 p.

Chowns, T. M., and Elkins, J. E. 1971, Origin of geodes from the Fort Payne Formation, Woodbury, Tennessee: Geol. Soc. America Abs. with Programs, v. 3, no. 5, p. 303.

Clarke, J. M., 1904, Naples fauna in western New York: New York State Mus. Mem. 6, p. 199-454.

Clarke, M. K., 1969, The Farmers Siltstone: a flysch-like deposit in northeastern Kentucky: Lexington, unpub. M. S. thesis, Univ. Kentucky, 69 p.

Cline, L. M., 1970, Sedimentary features of Late Paleozoic flysch, Ouachita Mountains, Oklahoma, in Lajoie, J., ed., Flysch sedimentology in North America: Geol. Assoc. Canada, Spec. Paper 7, p. 85-101.

Coleman, J. M., and Gagliano, S. M., 1965, Sedimentary structures: Mississippi River deltaic plain, in Middleton, G. V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 133-148.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga Shale and related rocks of central Tennessee and nearby areas: U.S. Geol. Survey Prof. Paper 357, 91 p.

Conkin, J. E., 1954, Hyperammina Kentuckyensis n. sp. from the Mississippian of Kentucky, and discussion of Hyperammina and Hyperamminoides; Cushman Foundation Foraminiferal Research Contrib. v. 5, pt. 4, no. 119, p. 165-169, pl. 31.

Conkin, J. E., 1956, Hyalostelia ancora Gutschick in the Mississippian of Indiana and Kentucky: Am. Midland Naturalist, v. 56, p. 430-433.

________ 1957, Stratigraphy of the New Providence Formation (Mississippian) in Jefferson and Bullitt Counties, Kentucky, and fauna of the Coral Ridge Member: Bulls. Am. Peleontology, v. 38, no. 168, p. 109-157.

________ 1960, Mississippian smaller foraminifera of southern Indiana, Kentucky, northern Tennessee, and south-central Ohio: Cincinnati, unpub. Ph. D. thesis, Univ. Cincinnati, 413 p.

Conkin, J. E., and Conkin, B. M., 1968, Scalarituba missouriensis and its stratigraphic distribution: Univ. Kansas Paleontol. Contrib., Paper 31, 7 p.

Coulter, H. W., and Migliaccio, R. R., 1966, Effects of the earthquake of March 27, 1964, at Valdez, Alaska: U.S. Geol. Survey Prof. Paper 542-C, p. C1-C36.

Curray, J. R., 1969, Lecture 6. History of continental shelves, in Stanley, D. J., convener, The new concepts of continental margin sedimentation: AGI Short Course Lecture Notes, 7-9 November 1969, 18 p.

Curtis, D. M., 1970, Miocene deltaic sedimentation, Louisiana Gulf Coast, in Morgan, J. P., and Shaver, R. H., eds., Deltaic sedimentation modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 293-308.

Daly, R. A., 1936, Origin of submarine canyons: Am. Jour. Sci., 5th ser., v. 31, no. 186, p. 401-420.

Doeglas, D. J., 1950, De interpretatie van korrelgrootte-analysen: Verh. Ned. Geol. en Mijnb; Gen. Geol. ser., Deel 15, 2e stuuk., p. 247-328.

Dott, R. H., Jr., 1963, Dynamics of subaqueous gravity depositional processes: Am. Assoc. Petroleum Geologists Bull., v. 47, p. 104-128.

Dunbar, C. O., and Rogers, John, 1957, Principles of Stratigraphy: New York, John Wiley and Sons, 356 p.

Dzulynski, Stanislaw, and Simpson, Frank, 1966, Experiments on interfacial current markings: Geol. Rom., v. 5, p. 197-214.

Dzulynski, Stanislaw and Walton, E. K., 1965, Sedimentary features of flysch and greywackes: Amsterdam, Elsevier 274 p.

Emery, K. O., 1960, The sea off Southern California: a modern habitat of petroleum: New York, John Wiley and Sons, 366 p.

Emery, K. O., and Bray, E. E., 1962, Radiocarbon dating of California basin sediments: Am. Assoc. Petroleum Geologists Bull., v. 46, 1839-1856.

Enos, Paul, 1969, Anatomy of a flysch: Jour. Sedimentary Petrology, v. 39, p. 680-723.

Ericson, D. B., Ewing, Maurice, and Heezen, B. C., 1952, Turbidity currents and sediments in North Atlantic: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 489-511.

Ewing, Maurice, Ericson, D. B., and Heezen, B. C., 1958, Sediments and topography of the Gulf of Mexico, in Weeks, Lewis., ed., Habitat of oil: Tulsa, Am. Assoc. Petroleum Geologists, p. 995-1053.

Fisk, H. N., 1961, Bar-finger sands of Mississippi delta, in Peterson, J. A., and Osmond, J. C., eds., Geometry of sandstone bodies: Tulsa, Am. Assoc. Petroleum Geologists, p. 29-52.

Folk, R. L., 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: Jour. Geology, v. 62, p. 344-359.

________ 1958, Petrology of sedimentary rocks: Austin, Hemphills, 170 p.

Folk, R. L., and Ward, W. C., 1957, Brazos River bar: a study in the significance of grain size parameters: Jour. Sedimentary Petrology, v. 27, p. 3-26.

Frakes, L. A., 1967, Stratigraphy of the Devonian Trimmers Rock in eastern Pennsylvania: Pennsylvania Geol. Survey Bull. G51, 208 p.

Friedman, G. M., 1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: Jour. Sedimentary Petrology, v. 37, p. 327, 354.

Gilbert, C. M., 1954, Sedimentary rocks p. 251-384, in Williams, H., Turner, F. J., and Gilbert, C. M., Petrography: San Francisco, W. H. Freeman and Co., 406 p.

Gorsline, D. S., and Emery, K. O., 1959, Turbidity-current deposits in San Pedro and Santa Monica basins off southern California: Geol. Soc. America Bull., v. 70, p. 279-290.

Grabau, A. W., and O'Connell, Marjorie, 1917, Were the graptolite shales, as a rule, deep or shallow water deposits?: Geol. Soc. America Bull., v. 28, p. 959-964.

Greenman, N. N., and LeBlanc, R. J., 1956, Recent marine sediments and environments of northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 813-847.

Gutenberg, Beno, 1939, Tsunamis and earthquakes: Seismol. Soc. America Bull., v. 29, p. 517-526.

Gutschick, R. C., 1954, Sponge spicules from the Lower Mississippian of Indiana and Kentucky: Am. Midland Naturalist, v. 52, p. 501-509.

Hails, J. R., and Hoyt, J. H., 1969, The significance and limitations of statistical parameters for distinguishing ancient and modern sedimentary environments of the lower Georgia Coastal Plain: Jour. Sedimentary Petrology, v. 39, p. 559-580.

Haner, B. E., 1971, Morphology and sediments of Redondo Submarine Fan, southern California: Geol. Soc. America Bull., v. 82, p. 2413-2432.

Häntzschel, Walter, 1962, Trace fossils and Problematica, in Moore, R. C., ed., Treatise on invertebrate paleontology--Pt. W., Miscellanea: New York, Geol. Soc. America (and Univ. Kansas Press), p. W177-W245.

Harms, J. C., and Fahnestock, R. K., 1965, Stratifications, bed forms, and flow phenomena (with an example from the Rio Grande), in Middleton, G. V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 84-115.

Harrison, J. E., and Grimes, D. J., 1970, Mineralogy and geochemistry of some Belt rocks, Montana and Idaho: U.S. Geol. Survey Bull. 1312-O, 49 p.

Heezen, B. C., 1956, Corrientes de turbidez del Rio Magdalena: Soc. Geog. Colombia Bol., v. 51-52, p. 135-143.

Heezen, B. C., and Drake, C. L., 1964, Grand Banks slump: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 221-225.

Heezen, B. C., and Ewing, Maurice, 1952, Turbidity currents and submarine slumps, and the 1929 Grand Banks earthquake: Am. Jour. Sci., v. 250, p. 849, 873.

________ 1955, Orleansville earthquake and turbidity currents: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 2505-2514.

Hjulström, Filip, 1939, Transportation of detritus by moving water, in Trask, P. D., ed., Recent marine sediments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 4, p. 5-31. [1955]

Houtz, R. E., 1962, The 1953 Suva earthquake and tsunami: Seismol. Soc. America Bull., v. 52, p. 1-12.

Hrabar, S. V., Kepferle, R. C., Klekamp, C. T., Pryor, W. A., and Potter, P. E., 1971, Knifley Sandstone: Early Mississippian infralittoral sandstone body [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 344-345.

Hsu, K. J., 1960, Paleocurrent structures and paleogeography of the ultra-helvetic flysch basins, Switzerland: Geol. Soc. America Bull., v. 71, p. 577-610.

_______ 1970, The meaning of the word flysch--a short historical search, in Lajoie, J., ed., Flysch sedimentology in North America: Geol. Assoc. Canada, Spec. Paper 7, p. 1-11.

Huang, Ter-chien, and Goodell, H. G., 1970, Sediments and sedimentary processes of eastern Mississippi cone, Gulf of Mexico: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 2070-2100.

Hubert, J. F., 1967, Sedimentology of Prealpine flysch sequences, Switzerland: Jour. Sedimentary Petrology, v. 37, p. 885-907.

Hughes, P. W., Bradley, W. F., and Glass, H. D., 1960, Mineralogical analysis of carbonate rocks by X-ray diffraction: Jour. Sedimentary Petrology, v. 30, p. 619-622.

Inman, D. L., 1952, Measures for describing the size distribution of sediments: Jour. Sedimentary Petrology, v. 22, p. 123-145.

Israelsky, M. C., 1949, Oscillation chart: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 92-98.

James, Gerard, W., 1971, Depositional environment of widespread Pennsylvanian black shale (Excello) [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 345.

Kearby, J. K., 1971, The Cowbell Member of the Borden Formation (Lower Mississippian) of northeastern Kentucky: a delta front deposit: Lexington, unpub. M.S. thesis, Univ. Kentucky, 89 p.

Kepferle, R. C., 1966, Geologic map of the Howardstown quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-505.

_______ 1968a, Geologic map of the Shepherdsville quadrangle, Bullitt County, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-740.

_______ 1968b, Turbidites in the Lower Mississippian Borden Formation of central Kentucky [abs.]: Geol. Soc. America Spec. Paper 115, Abs. for 1967, p. 390-391.

_______ 1969, Geologic map of the Samuels quadrangle, north-central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-824.

_______ 1971, Members of the Borden Formation (Mississippian) in north-central Kentucky: U.S. Geol. Survey Bull. 1354-B, p. B1-B18.

_______ 1972a, Geologic map of the Valley Station quadrangle and part of the Kosmosdale quadrangle, north-central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-962.

_______ 1972b, Geologic map of the Brooks quadrangle, Bullitt and Jefferson Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-961.

_______ 1972c, Geologic map of the Raywick quadrangle, south-central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-1048. (In press.)

Kimura, Toshio, 1966, Thickness distribution of sandstone beds and cyclic sedimentations in the turbidite sequences at the localities in Japan: Tokyo Univ. Earthquake Research Inst. Bull., v. 44, p. 561-607.

Klepser, H. J., 1937, The Lower Mississippian rocks of the eastern Highland Rim: Ohio State Univ. Abs. Doctoral Dissert., v. 24, p. 181-187.

Krumbein, W. C., 1937, Sediments and exponential curves: Jour. Geology, v. 45, p. 577-601.

________1938, Size frequency distributions and the normal phi curve: Jour. Sedimentary Petrology, v. 8, p. 84-90.

Krumbein, W. C., and Garrels, R. M., 1952, Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials: Jour. Geology, v. 60, p. 1-33.

Krumbein, W. C., and Sloss, L. L., 1963, Stratigraphy and sedimentation: San Francisco, W. H. Freeman and Co., 2nd ed., 660 p.

Kuenen, Ph. H., 1953, Significant features of graded bedding: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 1044-1066.

________ 1964, Deep sea sands and ancient turbidites, in Bouma, A. H., and Brouwer, A., eds., Turbidites: Amsterdam, Elsevier, p. 3-33.

Lapworth, Charles, 1889, On the Ballantrae rocks of south Scotland and their place in the upland sequence: Geol. Mag., new ser., v. 6, p. 20-24, 59-69.

Lewis, R. Q., Sr., 1971, Geologic map of the Delmer quadrangle, Pulaski County, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-908.

Lineback, J. A., 1966, Deep-water sediments adjacent to the Borden Siltstone (Mississippian) delta in southern Illinois: Illinois Geol. Survey Circ. 401, 48 p.

_______ 1968a, Turbidites and other sandstone bodies in the Borden Siltstone (Mississippian) in Illinois: Illinois Geol. Survey Circ. 425, 29 p.

_______ 1968b, Subdivisions and depositional environments of New Albany Shale (Devonian-Mississippian) in Indiana: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 1291-1303.

_______ 1969, Illinois basin--sediment-starved during Mississippian: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 112-126.

Love, L. G., 1969, Sulphides of metals in recent sediments, in Sedimentary ores: ancient and modern (revised); Proc. 15th Inter-University Geological Congress, 1967: Leicester, England, Dept. Geology, Univ. Leicester, p. 31-60.

Lovell, J. P. B., 1970, The palaeogeographic significance of lateral variations in the ratio of sandstone to shale and other features of the Aberystwyth Grits: Geol. Mag., v. 107, p. 147-158.

Martinsson, Anders, 1970, Toponomy of trace fossils, in Crimes, T. P., and Harper, J. C., eds., Trace fossils: Geol. Jour. Spec. Issue 3, p. 323-330.

Mathews, W. H., and Shepard, F. P., 1962, Sedimentation of Fraser River delta, British Columbia: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 1416-1443.

McBride, E. F., 1962, Flysch and associated beds of the Martinsburg Formation (Ordovician), central Appalachians: Jour. Sedimentary Petrology, v. 32, p. 39-91.

McBride, E. F., Weidie, A. E., and Wolleben, J. A., 1971, Deltaic origin of Difunta Group (Late Cretaceous to Paleocene) Parras basin, Coahuila and Nuevo León, Mexico [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 352.

McIver, N. L., 1970, Appalachian turbidites, in Fisher, G. W., Pettijohn, F. J., Reed, J. C. Jr., and Weaver, K. N., eds., Studies of Appalachian Geology; central and southern: New York, Interscience, John Wiley and Sons, p. 68-81.

McKinney, T. F., and Friedman, G. M., 1970, Continental shelf sediments of Long Island, New York: Jour. Sedimentary Petrology, v. 40, p. 213-248.

Meckel, L. D., 1970, Paleozoic alluvial deposition in the central Appalachians: a summary, in Fisher, G. W., Pettijohn, F. J., Reed, R. C., Jr., and Weaver, K. N., eds., Studies of Appalachian geology: central and southern: New York, Interscience, John Wiley and Sons, 460 p.

Meischner, K. D., 1964, Allodapische Kalke, Turbidite in Riff-nahen Sedimentations-Becken, in Bouma, A. H., and Brouwer, A., eds., Turbidites: Amsterdam, Elsevier, p. 156-191.

Moiola, R. J., and Weiser, D., 1968, Textural parameters--An evaluation: Jour. Sedimentary Petrology, v. 38, p. 45-53, p. 957.

Moore, B. R., and Clarke, M. K., 1970, The significance of a turbidite sequence in the Borden Formation (Mississippian) of eastern Kentucky and southern Ohio, in Lajoie, J., ed., Flysch sedimentology in North America: Geol. Assoc. Canada, Spec. Paper 7, p. 211-218.

Moore, G. T., and Asquith, D. O., 1971, Delta: term and concept: Geol. Soc. America Bull., v. 82, p. 2563-2567.

Moore, R. C., 1949, Meaning of facies, in Longwell, C. R., Chmn, Sedimentary facies in geologic history: Geol. Soc. America Mem. 39, p. 1-34. [1964]

Morgenstern, N. R., 1967, Submarine sliding and the initiation of turbidity currents, in Richards, A. F., ed., Marine geotechnique: Urbana, Univ. Illinois Press, p. 189-220.

Nederlof, M. H., 1959, Structure and sedimentology of the Upper Carboniferous of the upper Pisuega Valley, Spain: Leidse Geol. Meded. v. 24, p. 603-703.

Parea, G. C., 1965, Evoluzione della parte settentrionale della geosynclinale appennica dall'Albiano all'Eocene Superiore: Atti Mem. Acc. Naz. Sc. Lett. Arti Modena, v. 7, p. 5-97.

Passega, R., 1957, Texture as characteristic of clastic deposition: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1952-1984.

Passega, R., 1962, Problem of comparing ancient with recent sedimentary deposit: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 114-118.

Passega, R., and Byramjee, R., 1969, Grain-size image of clastic deposits: Sedimentology, v. 13, p. 233-252.

Pepper, J. F., de Witt, Wallace, Jr., and Demarest, D. F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian basin: U.S. Geol. Survey Prof. Paper 259, 111 p.

Peterson, W. L., 1966a, Geologic map of the New Haven quadrangle, Nelson and Larue Counties, Kentucky: U.S. Geol. Survey, Geol. Quad. Map GQ-506.

_______ 1966b, Geologic map of the Nelsonville quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-564.

_______ 1967, Geologic map of the Lebanon Junction quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-603.

_______ 1968, Geologic map of the Cravens quadrangle, Bullitt and Nelson Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-737.

_______ 1972, Geologic map of the Loretto quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-1034. (In Press)

Peterson, W. L., and Kepferle, R. C., 1970, Deltaic deposits of the Borden Formation in central Kentucky, in Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700-D, p. D49-D54.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper and Row, 718 p.

Pettijohn, F. J. and Potter, P. E., 1964, Atlas and glossary of primary sedimentary structures: New York, Springer-Verlag, 370 p.

Phleger, F. B., 1951, Displaced foraminifera faunas, in Turbidity currents and the transportation of coarse sediments to deep water--a symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 2, p. 66-75.

Picard, M. C., 1971, Classification of fine-grained sedimentary rocks: Jour. Sedimentary Petrology, v. 41, p. 179-195.

Piper, J. W., and Normark, W. R., 1971, Re-examination of a Miocene deep-sea fan and fan-valley, southern California: Geol. Soc. America Bull., v. 82, p. 1823-1830.

Potter, P. E., Nosow, Edmund, Smith, N. M., Swann, D. H., and Walker, F. H., 1958, Chester cross-bedding and sandstone trends in Illinois basin: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 1013-1046.

Potter, P. E., and Pettijohn, F. J., 1963, Paleocurrents and basin analysis: Berlin, Springer-Verlag, 296 p., 30 pls.

Potter, P. E., and Pryor, W. A., 1961, Dispersal centers of Paleozoic and later clastics of the Upper Mississippi Valley and adjacent areas: Geol. Soc. America Bull., v. 72, p. 1195-1249.

Potter, P. E., and Siever, Raymond, 1956, Sources of basal Pennsylvanian sediments in the Eastern Interior Basin 1. Crossbedding: Jour. Geology, v. 64, p. 225-244.

Pryor, W. A., 1961, Sand trends and paleoslope in Illinois Basin and Mississippi Embayment, in Peterson, J. A., and Osmond, J. C., eds., Geometry of sandstone bodies: Tulsa, Am. Assoc. Petroleum Geologists, p. 119-133.

Reeves, J. R., 1922, Preliminary report on the oil shales of Indiana: Indiana Dept. Conservation, Div. Geology, Handbook of Indiana Geology, pt. 6, p. 1059-1105.

Rich, J. L., 1950, Flow markings, groovings, and intrastratal crumplings as criteria for recognition of slope deposits, with illustrations from Silurian rocks of Wales: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 717-741.

________ 1951a, Three critical environments of deposition, and criteria for recognition of rocks deposited in each of them: Geol. Soc. America Bull., v. 62, p. 1-19.

________ 1951b, Probable fondo origin of Marcellus-Ohio-New Albany-Chattanooga bituminous shales: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 2017-2040.

Rich, J. L., and Wilson, W. J., 1950, Paleogeographic and stratigraphic significance of subaqueous flow markings in the Lower Mississippian strata of south-central Ohio and adjacent parts of Kentucky [abs.]: Geol. Soc. America Bull., v. 61, p. 1496.

Rittenhouse, Gordon, 1946, Map showing distribution of several types of Berea sand in West Virginia, eastern Ohio, and western Pennsylvania: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 58.

Rusnak, G. A., 1957, A fabric and petrologic study of the Pleasantview Sandstone: Jour. Sedimentary Petrology, v. 27, p. 41-55.

Ryan, W. B. F., and Heezen, B. C., 1965, Ionian Sea submarine canyons and the 1908 Messina turbidity current: Geol. Soc. America Bull. v. 76, p. 915-932.

Sable, E. G., 1970, Source areas of Lower Mississippian red beds in eastern midcontinent, in Geological Survey research, 1970; U.S. Geol. Survey Prof. Paper 700-D, p. D88-D91.

Sable, E. G., Kepferle, R. C., and Peterson, W. L., 1966, Harrodsburg Limestone in Kentucky: U.S. Geol. Survey Bull. 1224-I, 12 p.

Sanders, J. E., 1960, Origin of convoluted laminae: Geol. Mag., v. 97, p. 409-421.

Schultz, L. G., 1964, Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale: U.S. Geol. Survey Prof. Paper 391-C, p. C1-C31.

Schwarzacher, Walter, 1958, The stratification of the Great Scar Limestone in the Settle District of Yorkshire: Liverpool and Manchester Geol. Jour., v. 2, p. 124-142.

Scott, K. M., 1966, Sedimentology and dispersal pattern of a Cretaceous flysch sequence, Patagonian Andes, southern Chile: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 72-107.

Scruton, P. C., 1960, Delta building and the deltaic sequence, in Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Am. Assoc. Petroleum Geologists, p. 82-102.

Sedimentation Seminar, 1966, Crossbedding in the Salem Limestone of central Indiana: Sedimentology, v. 6, p. 95-114.

_______ 1969, Bethel Sandstone (Mississippian) of western Kentucky and south-central Indiana, a submarine-channel fill: Kentucky Geol. Survey, ser. 10, Rept. Inv. 11, 24 p.

_______ 1972, Sedimentology of the Mississippian Knifley Sandstone and Cane Valley Limestone of south-central Kentucky: Kentucky Geol. Survey, ser. 10, Rept. Inv. (in preparation)

Seilacher, Adolf, 1953, Studien zur Palichnologie. I. Über die Methoden der Palichnologie: Neues Jahrb. Geol. u Päläont., Abhandl., v. 96, p. 421-452.

_______ 1967, Bathymetry of trace fossils: Marine Geology, v. 5, p. 413-428.

Shaw, D. B., and Weaver, C. E., 1965, The mineralogical composition of shales: Jour. Sedimentary Petrology, v. 35, p. 213-222.

Shepard, F. P., 1951, Transportation of sand into deep water, in Turbidity currents and the transportation of coarse sediments to deep water--a symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 2, p. 53-65.

_______ 1955, Delta-front valleys bordering the Mississippi distributaries: Geol. Soc. America Bull., v. 66, p. 1489-1498.

Shepard, F. P., Dill, R. F., and von Rad, Ulrich, 1969, Physiography and sedimentary processes of La Jolla submarine fan and fan valley, California: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 390-420.

Simons, D. B., Richardson, E. V., and Nordin, C. F., Jr., 1965, Sedimentary structures generated by flow in alluvial channels, in Middleton, G. V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, p. 34-52.

Sindowski, K. H., 1958, Die symoptische Methode des Korkuryen-Vergleiches zur Aussenzug foffiler Sedimentationsräume: Geol. Jahrb., v. 73, p. 235-275.

Sloss, L. L., 1962, Stratigraphic models in exploration: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 1050-1057.

Smith, N. M., 1965, The Sanders Group and subjacent Muldraugh Formation (Mississippian) in Indiana: Indiana Geol. Survey Rept. Prog. 29, 20 p.

Snavely, P. D., Jr., Wagner, H. C., and MacLeod, N. S., 1964, Rhythmic-bedded eugeosynclinal deposits of the Tyee Formation, Oregon Coast Range: Kansas Geol. Survey Bull. 169, p. 461-480.

Stanley, D. J., and Huang, Ter-Chien, 1971, Multiple origin of hemipelagic mud fill in Mediterranean basin [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 365.

Stockdale, P. B., 1931, The Borden (Knobstone) rocks of southern Indiana: Indiana Dept. Conserv., Div. Geology, Pub. 98, 330 p.

________ 1939, Lower Mississippian rocks of the east-central interior: Geol. Soc. America Spec. Paper 22, 248 p.

Sujkowski, Zb. L., 1957, Flysch sedimentation: Geol. Soc. America Bull. v. 68, p. 543-553.

Sullwold, H. H., Jr., 1960, Tarzana Fan, deep submarine fan of Late Miocene age, Los Angeles County, California: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 433-457.

_______ 1961, Turbidites in oil exploration, in Peterson, J. A., and Osmond, J. C., eds., Geometry of sandstone bodies: Tulsa, Am. Assoc. Petroleum Geologists, p. 63-81.

Swann, D. H., Lineback, J. A., and Frund, Eugene, 1965, The Borden Siltstone (Mississippian) delta in southwestern Illinois: Illinois Geol. Survey Circ. 386, 20 p.

ten Haaf, E., 1956, Significance of convolute lamination: Geol. en Mijnbouw, n. ser., v. 18, p. 188-194.

Thaden, R. E., Lewis, R. Q., Sr., Cattermole, J. M., and Taylor, A. R., 1961, Reefs in the Fort Payne Formation of Mississippian age, south-central Kentucky, in Geological Survey research, 1961: U.S. Geol. Survey Prof. Paper 424-B, p. B88-B90.

Thomson, A. F., 1971, Continuity of Pliocene turbidite sandstones, Ventura area, California, with applications to supplemental recovery [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 366-367.

Thomson, A. F., and Thomasson, M. R., 1969, Shallow to deep water facies development in the Dimple Limestone (Lower Pennsylvanian), Marathon region, Texas, *in* Friedman, G. M., ed., Depositional environments in carbonate rocks: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 14, p. 57-78.

Twenhofel, W. H., 1939, Environments of origins of black shales: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1178-1198.

Ulrich, E. O., 1911, Revision of the Paleozoic systems: Geol. Soc. America Bull., v. 22, 281-680.

Visher, G. S., 1965, Use of vertical profile in environmental reconstruction: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 41-61.

________ 1969, Grain size distributions and depositional processes: Jour. Sedimentary Petrology, v. 39, p. 1074-1106.

Walker, R. G., 1966a, Deep channels in turbidite-bearing formations: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1899-1917.

________ 1966b, Shale Grit and Grindslow Shales: transition from turbidite to shallow water sediments in the Upper Carboniferous of northern England: Jour. Sedimentary Petrology, v. 36, p. 90-114.

________ 1967, Turbidite sedimentary structures and their relationship to proximal and distal depositional environments: Jour. Sedimentary Petrology, v. 37, p. 25-43.

Walker, R. G., 1970, Review of the geometry and facies organization of turbidites and turbidite-bearing basins, in Lajoie, J., ed., Flysch sedimentology in North America: Geol. Assoc. Canada, Spec. Paper 7, p. 219-251.

________ 1971, Nondeltaic depositional environments in the Catskill clastic wedge (Upper Devonian) of central Pennsylvania: Geol. Soc. America Bull., v. 82, p. 1305-1326.

Walker, R. G., and Harms, J. C., 1971, The "Catskill Delta"--a prograding muddy shoreline in central Pennsylvania: Jour. Geology v. 79, p. 381-399.

Walther, Johannes, 1893-94, Einleitung in die Geologie als historische Wissenschaft; Beobachtungen uber die Bildung der Gesteine und ihrer organischen Einschlusse, bd. 1: Jena, G. Fischer.

Warren, P. T., 1963, The petrography, sedimentation and provenance of the Wenlock rocks near Hawick, Roxburghshire: Edinburgh Geol. Soc. Trans., v. 19, p. 225-255.

Warshaw, C. M., and Roy, Rustum, 1961, Classification and a scheme for the identification of layer silicates: Geol. Soc. America Bull., v. 72, p. 1455-1492.

Weiler, Yehezkiel, 1970, Mode of occurrence of pelites in the Kythrea Flysch basin (Cyprus): Jour. Sedimentary Petrology, v. 40, p. 1255-1261.

Weir, G. W., 1970, Borden Formation (Mississippian) in southeast-central Kentucky in Geol. Soc. America, Southeastern Sec. 18th Annual Mtg. 1970, Guidebook for field trips: Lexington, Ky., Kentucky Geol. Survey, p. 29-48.

Weir, G. L., Gualtieri, J. L., and Schlanger, S. O., 1966, Borden Formation (Mississippian) in south- and southeast-central Kentucky: U.S. Geol. Survey Bull. 1224-F, 38 p.

Weller, Stuart, 1898, Classification of the Mississippian Series: Jour. Geology, v. 6, p. 303-314.

Wells, J. W., Association of crinoids with Callixylon in the lower Ohio Shale: Am. Jour. Sci., v. 239, p. 454-456.

Wilson, J. L., 1969, Discussion, in Friedman, G. M., ed., Depositional environments in carbonate rocks: Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. 14, p. 18.

Wilson, W. J., 1950, Subaqueous flow markings in the Lower Mississippian strata of south-central Ohio and adjacent parts of Kentucky: Cincinnati, unpub. M.S. thesis, Univ. Cincinnati, 37 p.

Young, G. A., 1926, Geology and economic minerals of Canada: Canada Geol. Survey, Econ. Geology ser., no. 1 (Pub. no. 2065)

APPENDIX A

MEASURED SECTIONS

Locations of all sections included below are shown on figure 7. Measurements were made using hand level, tape, and barometer. Contacts between gradational units are somewhat arbitrary. The thicknesses of units separated by arbitrary contacts are subject to modification by detailed geologic mapping, particularly in this category are the sections measured in Indiana, where detailed geologic maps are not available.

Bald Knob section

[Reconnaissance section of the Borden Formation on Bald Knob Road, measured from the junction with Fairview Knob Road near the center of sec. 35, T. 1 S., R. 6 E., Floyd County, Ind. (Speed quadrangle)]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Muldraugh Member (incomplete):	
10. Soil, moderate reddish orange and dark to pale yellowish orange; cherty; typical residuum of Muldraugh Member--	10±
Edwardsville Member of Smith (1965):	
9. Siltstone and shale, greenish-gray to yellowish-gray; two massive siltstone beds are without visible laminae------	32
8. Covered; includes interval of Floyds Knob bed------------------------------	13
Total Edwardsville Member of Smith (1965)----------------------------	45

Mississippian--Continued Borden Formation--Continued	Thickness (feet)
Holtsclaw Siltstone Member:	
7. Siltstone, light olive gray; weathers yellowish gray; alternately shaly and massive; planar laminae in upper 33 ft-	103
6. Siltstone, as above, massive-weathering; iron-stained limestone concretions numerous along three horizons----------	11
Total Holtsclaw Siltstone Member-----	114
Nancy Member:	
5. Siltstone, clayey, light olive gray; massive and resistant in ditch, shaly-weathering in banks above road; heavily limonite-stained locally---------------	53
4. Covered----------------------------------	21
3. Shale, silty, olive-gray to medium-gray; slightly calcareous; tends to slump----	37
Total Nancy Member------------------	111
New Providence Shale Member (incomplete):	
2. Clay shale, olive-gray to light olive gray and greenish-gray; conchoidal fracture where fresh; contains sideritic "ironstone" concretions 0.3 ft in diameter; slopes on unit become less steep towards base as silt content decreases-----------------------------	35
1. Covered to base of ravine; upper 10 ft partly exposed; like unit above--------	55+
Total New Providence Shale Member----	90+
Total Borden Formation---------------	370+

Base of section elev 605 ft by altimeter. Inferred base of Borden Formation at elev 425 ft.

Flat Run section

[Reconnaissance section of the Borden Formation down Green Valley Road from junction (elev 978 ft) at the top of the Knobstone escarpment near the center of sec. 10, T. 2 S., R. 6 E., Floyd County, Ind. (New Albany quadrangle)]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Muldraugh Member (incomplete):	
16. Covered; may include residue of Harrodsburg Limestone	20±
15. Soil, moderate reddish orange and dark to pale yellowish orange; contains silicified crinoidal remains	6
Total Muldraugh Member	26±
Edwardsville Member of Smith (1965):	
14. Siltstone, planar-bedded ledges stand out from more massive-weathering beds	40
Floyds Knob bed:	
13. Silt shale, glauconitic	0.1
12. Limestone, fossil-fragmental; irregular bedding	1.2
11. Shale, olive-gray, silty; glauconitic concentration at base	8
Total Floyds Knob bed	9.3
Holtsclaw Siltstone Member:	
10. Siltstone, massive weathering	30
9. Siltstone, containing zones of planar-laminated bedding generally less than 0.2 ft thick	17
8. Siltstone, shaly weathering in part; gradational with underlying unit	28
Total Holtsclaw Siltstone Member	75

Mississippian--Continued
Borden Formation--Continued

	Thickness (feet)
Nancy Member:	
7. Shale, silty; tendency to slump increases toward the base	168
Kenwood Siltstone Member:	
6. Siltstone, in planar resistant bed	0.2
5. Shale	0.1
4. Siltstone, penetrated by vertical burrow	0.3
3. Shale	0.1
2. Siltstone, smooth base	0.4
Total Kenwood Siltstone Member	1.1
New Providence Shale Member(incomplete):	
1. Shale, greenish-gray, mostly covered and slumped to creek bed below	60+
Total Borden Formation	379+

Pleiss Hollow section

[Section of Kenwood Siltstone Member of the Borden Formation. Measured down north side of private road up Pleiss Hollow, 0.1 mile north of Indiana State Highway 62, SE 1/4, NW 1/4, NE 1/4 sec. 5, T. 3 S., R. 6 E., Floyd County, Ind. (New Albany quadrangle)]

Mississippian:
Borden Formation (incomplete):

	Thickness (feet)
Kenwood Siltstone Member:	
15. Shale, greenish-gray, silty	5.0+
14. Siltstone, weathered yellowish gray; shale parting in upper third	0.6
13. Shale	0.1

Mississippian--Continued
Borden Formation--Continued

		Thickness (feet)
Kenwood Siltstone Member--Continued		
12.	Siltstone, basal groove 55°-235°--------	0.4
11.	Shale------------------------------------	0.1
10.	Siltstone; top burrowed; incipient bedding-plane parting------------------	0.3
9.	Shale------------------------------------	0.8
8.	Siltstone, planar- and ripple-bedded (pl. 6)-------------------------------	1.5
7.	Shale------------------------------------	0.7
6.	Siltstone, poorly exposed---------------	0.6
5.	Shale------------------------------------	7
4.	Siltstone, basal groove 70°-250°--------	0.9
3.	Shale------------------------------------	1.7
2.	Siltstone, basal groove 87°-267°--------	0.7
	Total Kenwood Siltstone Member--------	20.4+
New Providence Shale Member (incomplete):		
1.	Shale, greenish-gray--------------------	2+
	Total Borden Formation-----------------	22+

Pigeon Roost section
(location designated by clay pit symbol, fig. 7)

[Section of Kenwood Siltstone Member of Borden Formation. Measured down north face of pit on nose south of Pigeon Roost hill at end of haulage road about 0.4 mile north of Fivemile Road, 0.4 mile west of Indiana State Highway 111, about 6.2 miles southwest of New Albany City Hall in NE 1/4, SW 1/4 sec. 29, T. 3 S., R. 6 E., Floyd County, Ind. (Lanesville quadrangle)]

Mississippian:
Borden Formation (incomplete):

	Thickness (feet)
Upper tongue of New Providence Shale Member:	
17. Shale, greenish-gray, overlain by 4 ft sequence of surficial deposits (not included)	8.0+
Kenwood Siltstone Member:	
16. Siltstone, basal grooves 85°-265°; vertical joints strike 3°	0.6
15. Shale	1.6
14. Siltstone	0.3
13. Shale	5.0
12. Siltstone	0.1
11. Shale parting, thin seam	
10. Siltstone	0.1
9. Shale	0.7
8. Siltstone, shaly	0.2
7. Shale parting, thin seam	
6. Siltstone, basal groove 80°-260°	0.7
5. Shale	0.6
4. Siltstone	0.2
3. Shale	0.1
2. Siltstone, upper 0.2 ft limonite-cemented; basal grooves 70°-250°	0.5
Total Kenwood Siltstone Member	10.7
Lower tongue of New Providence Shale Member (incomplete):	
1. Shale, dark-gray; weathers light gray; contains four zones of sideritic concretions, some with sphalerite	10.7+
Total Borden Formation	29.4+

Quillman Hill section

[Section of Kenwood Siltstone Member and upper part of New Providence Shale Member of the Borden Formation. Measured up bare southeast nose of hill west of Iroquois Park at end of private road 0.2 mile from junction with St. Andrews Church Road 0.7 mile west of junction with Palatka Road in southwest Louisville. Top of section on nose marked by 650-ft elev contour in Carter coordinate 4-T-45 in Louisville West quadrangle; 1,551,200 ft east, 243,600 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

Mississippian: Borden Formation (incomplete):	Thickness (feet)
10. Covered with loess soil to top of hill----	7+
Kenwood Siltstone Member:	
9. Mostly covered; some slumped siltstone blocks from beds less than 0.4 ft thick	13
8. Siltstone, basal grooves 40°-220°--------	0.1
7. Shale----------------------------------	0.8
6. Siltstone, basal grooves 65°-245°; cephalopod (orthoconic) oriented perpendicular to groove marks; <u>Cosmorhaphe</u>-like trace fossils in upper part of bed-----	0.3
5. Shale----------------------------------	0.1
4. Siltstone, basal prod casts 255°; vertical joints at 35°, 350°; large burrows in upper part form large depressions------	0.9
3. Shale----------------------------------	12.9
2. Siltstone, iron-stained, poorly preserved	0.2
Total Kenwood Siltstone Member---------	28.3
New Providence Shale Member (incomplete):	
1. Shale, greenish-gray, clayey, with scattered limonitic cemented layers along bedding plane------------------------	50.5+
Total Borden Formation--------------	85.8+

Iroquois Hill section, north
(loc. D)

[Section of Kenwood Siltstone and New Providence Shale Members of the Borden Formation. Measured down southwest face of nose below lookout point on northwest end of hill in Iroquois Park in southwest Louisville. Top of section at elev 712 ft by altimeter in Carter coordinate 23-U-45 in Louisville West quadrangle; 1,558,500 ft east, 246,700 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member (incomplete):	
12. Covered to road level-------------------	12.0+
11. Siltstone, base covered-----------------	3.0+
10. Shale, partly covered-------------------	2.0-
9. Siltstone, limonite-cemented------------	0.8
8. Siltstone; basal 0.2 ft planar laminated; basal groove 30°-210°-----------------	0.5
7. Shale----------------------------------	0.3
6. Siltstone, basal groove at 40°-220°; bed penetrated by vertical burrow 1 cm wide	0.5
5. Shale----------------------------------	0.1
4.1 Siltstone, basal groove at 60°-240°; vertical burrow as in unit 6----------	0.6
3. Shale, dark greenish gray to light olive gray (wet); weathers yellowish gray (dry)--------------------------------	19.8
2. Siltstone, moderate reddish brown to dark yellowish orange; may be slumped-	0.2
Total Kenwood Siltstone Member--------	39.8+
New Providence Shale Member (incomplete):	
1. Shale, greenish-gray, clayey------------	32.4+
Total Borden Formation----------------	72.2+

Iroquois Hill section, south
(loc. D')

[Section of Kenwood Siltstone and New Providence Shale Members of Borden Formation. Measured down south end of hill in Iroquois Park in southwest Louisville from shelter on nose above map contour elev 740 ft in Carter coordinate 3-T-45 in Louisville West quadrangle; 1,558,700 ft east, 243,000 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

Mississippian:
Borden Formation (incomplete):

Kenwood Siltstone Member:

		Thickness (feet)
24.	Covered by loess soil drape--------------	29
23.	Siltstone----------------------------------	1.6
22.	Shale--------------------------------------	1.6
21.	Siltstone, may be slumped; basal grooves 80°-260°--------------------------------	0.5
20.	Shale--------------------------------------	1.7
19.	Siltstone, basal grooves 95°-275°; vertical joints at 15°, 340°; locally thickens to 0.6 ft------------------------------	0.2
18.	Shale--------------------------------------	6.8
17.	Siltstone, basal grooves at 95°-275°; vertical joints strike 30° and 335°----	0.2
16.	Shale--------------------------------------	1.2
15.	Siltstone, yellowish-gray; grooves at 95°-275°; vertical joints strike 15° and 90°	0.4
14.	Shale--------------------------------------	0.7
13.	Siltstone, dark yellowish orange, limonite-stained from weathered iron sulfide?---	0.1
12.	Shale, silty, light olive gray, yellowish-gray and medium light gray-------------	11.5
11.	Siltstone; grades laterally to zone of sideritic "ironstone" concretions; upper surface contains Cosmorhaphe-like trace fossil---------------------------	0.4

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

	Thickness (feet)
Total Kenwood Siltstone Member---------------	55.9±

New Providence Shale Member (incomplete):

		Thickness (feet)
10.	Shale, partly covered; scattered siderite nodules; persistent nodule zone at base	23
9.	Shale, somewhat more silty than underlying unit; siderite concretions in zone 7.5 ft below top and at base------	15
8.	Shale; sideritic concretions in zone 1.5 ft above base and at base--------------	5
7.	Shale; sideritic concretions 2.3 ft above base-------------------------------------	10.1
6.	Siderite concretion zone; persistent; forms bench------------------------------	0.9
5.	Shale; siderite concretions 0.4 ft thick, olive gray inside, weather grayish brown to moderate yellowish brown in persistent zone at base and at 2.3 ft, 7.0 ft and 7.3 ft above base-----------	12.3
4.	Shale, clayey, olive-gray, more silty than is underlying unit----------------	33.2
3.	Cone-in-cone sideritic concretion layer; weathers pale brown to grayish brown in center with dark yellowish orange rind-	0.3
2.	Shale, clayey, dark greenish gray; weathers greenish gray to grayish yellow green or pale olive------------------------------	13.3
1.	Covered, probably similar to unit 2------	25+
	Total New Providence Shale Member-----	138.1+
	Total Borden Formation----------------	194 +

Kenwood Hill section

[Type section of Kenwood Siltstone Member of Borden Formation. Measured in abandoned quarry on northeast slope of Kenwood Hill in southwest Louisville. Top of section at bench mark (elev 755 ft) in Carter coordinate 2-T-45 of Louisville West quadrangle; 1,562,350 ft east, 242,800 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

Mississippian: Borden Formation (incomplete): Kenwood Siltstone Member (incomplete):	Thickness (feet)
15. Loess soil to top of hill; correlation with exposures in Iroquois Park less than a mile to the west indicates the top 20 feet of the Kenwood may have been lost here to erosion-------------	3.0
14. Shale, mostly covered-------------------	5.3
13. Siltstone, moderate yellowish brown to dark yellowish orange; limonite-stain; may be slumped (bed 7 of table 1)-----	0.2
12. Silt shale, olive-gray to greenish-gray-	4.5
11. Siltstone, yellowish-gray; basal groove 35°-215° (bed 6 of table 1)------------	1.0
10. Shale, silty, sample LW-1-54------------	0.7
9. Siltstone; sideritic concretions 0.8 ft in diameter weather to limonite about 2.5 ft above base; basal grooves and low load-casted rills with blunt end down-current at 195°, 200°, and 208° (bed 5 of table 1)-------------------	4.5
8. Shale, sample LW-1-44-------------------	0.8
7. Siltstone, planar laminated bedding; ostracode? test and shale chips in slab of sample from base; sole marks mainly grooves 165°-345° (bed 4 of table 1)------------------------------	6.5
6. Shale, sample LW-1-37------------------	0.3

Mississippian--Continued
Borden Formation--Continued

	Thickness (feet)
Kenwood Siltstone Member--Continued	
5. Siltstone; burrows numerous in top foot (bed 3 of table 1)----------------------	9.7
4. Shale; bedding plane surfaces show abundant *Cosmorhaphe*-like trace fossils as well as common *Scalarituba missouriensis* as much as a foot long-----------	1.4
3. Siltstone; limonite cement from weathered sideritic concretions in a zone 3.5 ft above base; planar lamination prominent 0.2 ft above base; ripple laminae of low relief in zone about 2.5 ft above base; short segment of vertical burrow at same horizon; brush marks on base 355°-175° (bed 2 of table 1)----------------------	5.0
2. Shale, partly covered, contains sideritic concretions 0.3 ft thick in zone 2.4 ft below top of bed; samples LW-1-7, -8, -9, and -10 --------------------------------	4.9
1. Siltstone, limonitic cement 2.5 ft to 3.5 ft below top of bed; basal 0.5 ft heavily limonite cemented and replaced, probably represents weathered iron sulfide; trace fossils abundant in upper foot (bed 1 of table 1)----------------------------	11.5
Total Kenwood Siltstone Member--------	59.3±
Total Borden Formation----------------	59.3+

Kenwood Hill section, south

[Section of Kenwood Siltstone and New Providence Shale Members of the Borden Formation. Top of section is on Kenwood Hill at elev 728 ft by hand level, 1,100 ft south of type section, in Carter coordinate 2-T-45 in Louisville West quadrangle; 1,562,400 ft east, 241,600 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

Mississippian:
Borden Formation (incomplete):

		Thickness (feet)
Kenwood Siltstone Member:		
13.	Shale--	2+
12.	Siltstone; slumped----------------------	1-
11.	Shale--	2
10.	Siltstone; inclined burrows 3 cm wide at top; basal grooves 110°-290°; prod cast 290°----------------------------	1.5
9.	Shale--	1.0
8.	Siltstone; laminated in upper part; low flute cast 315° (sample LW-2T, 2B)	2.1
7.	Shale--	0.5
6.	Siltstone, low flute cast 330°----------	1.2
5.	Shale--	7.2
4.	Siltstone---------------------------------	1.0
3.	Shale, silty-----------------------------	8
2.	Siltstone, faintly laminated; sideritic concretions in basal part of upper half of bed; sole marks obscured by limonitic replacement of pyrite; micro-ripples on surface of bed strike at 60°; vertical burrow in upper foot of bed--	3.2
	Total Kenwood Siltstone Member	30.7+
New Providence Shale Member (incomplete):		
1.	Shale, clayey, greenish-gray, to saddle below; base not exposed---------------	105+
	Total Borden Formation--------------	136+

Finley Hill section

[Section of Kenwood Siltstone and New Providence Shale Members of the Borden Formation. Measured along new road cut on the west side of Finley Hill in southwest Louisville; supplemented by exposures on the northwest end of the hill and in a trench for utilities on the southwest end of the hill. Top of section at map elev 706 ft in Carter coordinate 11-T-45 in Louisville West quadrangle; 1,560,700 ft east, 234,500 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
26. Covered by loess soil to top of hill------	8±
Kenwood Siltstone Member:	
25. Siltstone, poorly exposed---------------	1.4
24. Shale and siltstone, mainly covered-----	13
23. Shale and siltstone, partly covered, four siltstone beds less than 0.5 ft thick appear slightly slumped---------	3
22. Siltstone, basal grooves 170°-350°------	0.4
21. Shale-----------------------------------	4
20. Siltstone, basal grooves 180°-360°, top not exposed--------------------------	3+
19. Shale-----------------------------------	1
18. Siltstone, basal grooves at 180°-360°---	9.5
17. Shale-----------------------------------	1.6
16. Siltstone-------------------------------	6.8
15. Shale-----------------------------------	2.4
14. Siltstone, basal grooves 175° to 185°---	0.4
13. Shale-----------------------------------	3.5
12. Siltstone-------------------------------	0.1
11. Shale-----------------------------------	3.0

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
10.	Siltstone, grooves at 240°-60°----------	0.2
9.	Shale, clayey--------------------------	4.5
8.	Siltstone, massive bed, base not seen---	5+
	Total Kenwood Siltstone Member--------	62.8+
	New Providence Shale Member:	
7.	Shale, greenish-gray, exposed in cut----	34
6.	Covered, probably shale----------------	67
5.	Shale, greenish-gray, interbedded with pale red to pale brown shale; pelmatozoan debris abundant--------------	30
4.	Shale, greenish-gray, clayey------------	28
	Total New Providence Shale Member-----	159
	Total Borden Formation----------------	222+
	Rockford Limestone:	
3.	Dolomite, ferruginous, altered to heavily limonite-stained bed; weathers grayish orange to dark yellowish brown-----------	1.5
2.	Dolomite, as above, with concentration of glauconite and phosphatic nodules--------	0.2
1.	Shale, greenish-gray, altered to dark yellowish orange--------------------------------	0.4
	Total Rockford Limestone--------------	2.1

Devonian:
New Albany Shale: Not measured.

Waverly Park section

[Section of Holtsclaw Siltstone, Nancy, and Kenwood Siltstone Members of the Borden Formation. Measured along road leading in to Waverly Hills Park, less than 0.1 mile from junction with Arnoldtown Road, 1.9 miles east of Pleasure Ridge Park by way of St. Andrews Church Road; top of section on knoll (map elev 740 ft) west of road in Carter coordinate 6-T-45 in Louisville West quadrangle; 1,547,500 ft east, 234,600 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Holtsclaw Siltstone Member (incomplete):	
18. Siltstone, calcareous, clayey, medium-dark-gray to dark-gray; weathers light gray to yellowish gray; massive and tends to spall where fresh; weathers to fissile shaly chips; trace fossil <u>Scalarituba</u> <u>missouriensis</u> burrows 1 cm wide appear in cross section as dark clay-filled lenses with a convex upper surface and a planar lower surface; associated with smaller <u>Cosmorhaphe</u>-like traces and some vertical burrows--	40+
Nancy Member:	
17. Shale, silty, gradational with overlying unit----------------------------------	78
Kenwood Siltstone Member:	
16. Siltstone, possibly slumped-------------	0.6
15. Shale, mainly covered-------------------	24
14. Siltstone-------------------------------	0.6
13. Shale-----------------------------------	0.1
12. Siltstone-------------------------------	1.5
11. Shale-----------------------------------	1.1
10. Siltstone; basal grooves 65°-245°--------	0.2
9. Shale------------------------------------	4.5

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
8.	Siltstone, shale parting in middle-------	0.2
7.	Shale-------------------------------------	0.7
6.	Siltstone---------------------------------	0.1
5.	Shale-------------------------------------	0.1
4.	Siltstone, basal grooves at 65°-245°------	0.7
3.	Shale-------------------------------------	0.7
2.	Siltstone, limonite-stained; upper part contains trace fossils Scalarituba and Cosmorhaphe ---------------------------	0.2
	Total Kenwood Siltstone Member------- (base elev. 582 by altimeter)	35.3

New Providence Shale Member (incomplete):

		Thickness (feet)
1.	Shale, greenish-gray, partly covered to road level------------------------------	31+
	Tctal Borden Formation---------------	184+

South Park Hill section

[Section of the Kenwood Siltstone Member of the Borden Formation. Measured down private road leading to South Park Road from house one-half mile south at map elev 770 ft; top of section in Carter coordinate 17-T-46 in Brooks quadrangle; 1,574,400 ft east, 226,800 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Nancy Member (incomplete):	
20. Shale, silty, partly covered to hilltop-	20±
Kenwood Siltstone Member:	
19. Siltstone, basal grooves 55°-235°-------	0.3
18. Shale----------------------------------	2.5
17. Siltstone, faint internal lamination, vertical burrow; basal groove 70°-250°	0.2
16. Shale parting	
15. Siltstone, sideritic cement, vertical burrows; low flute casts 230°; merges with bed 17 laterally-----------------	0.5
14. Shale----------------------------------	2.2
13. Siltstone------------------------------	0.2
12. Shale parting	
11. Siltstone, sole marks with high relief but no directional indicators; bed thickens to 1.2 ft at expense of underlying shale, then thins along outcrop until normal thickness attained over a horizontal distance of 30 ft(channel-fill type I); lower 0.2 ft graded; planar horizontal laminae prominent, inclined laminae dip east on west side of channel; vertical burrow forks above base; *Chondrites*-like burrows and larger horizontal burrows common near top----------------------------------	0.5

Mississippian--Continued
Borden Formation--Continued

		Thickness (feet)
	Kenwood Siltstone Member--Continued	
10.	Shale------------------------------------	9.0
9.	Siltstone, large burrow penetrates top of bed at an angle; base of bed not exposed--------------------------------	1+
8.	Shale, partly covered-------------------	4
7.	Siltstone, penetrated by vertical burrows about 2 mm wide; brush casts on otherwise smooth basal surface 245°---------	0.3
6.	Shale, sideritic concretions in layer 3 ft above base-----------------------	13
5.	Siltstone, basal 0.05 ft planar laminated, vertical burrows penetrate bed; base smooth---------------------------------	0.6
4.	Shale; sideritic concretions in layer near middle; abundant _Scalarituba missouriensis_ prominent 3 ft below top-	15
3.	Siltstone, basal grooves at 45°-225°; center contains sideritic concretions; vertical burrows penetrated bed--------	0.7
2.	Shale------------------------------------	10
1.	Siltstone, heavily limonite-cemented (base at elev 690 ft by altimeter)-----	0.2
	Total Kenwood Siltstone Member-------	60.2
	New Providence Shale Member not described.	
	Total Borden Formation--------------	80.2+

Base of Borden Formation at elev 470 ft inferred from water well at top of hill.

Coral Ridge pit section

[Section of the Nancy and Kenwood Siltstone Members of the Borden Formation. Measured up face of pit east of brick plant 0.2 miles east of State Highway 1020; base of section in Carter coordinate 24-T-46 in Brooks quadrangle; 1,577,050 ft east, 218,600 ft north, Kentucky coordinate system, north zone, Jefferson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Nancy Member (incomplete):	
21. Siltstone and shale, poorly exposed to top of hill	103
20. Siltstone, single resistant-weathering ledge	25
19. Shale, silty	17
Total Nancy Member	145+
Kenwood Siltstone Member:	
18. Siltstone, resistant bed; laminated; sideritic cement	0.2
17. Shale	3.0
16. Siltstone	0.1
15. Shale	1.4
14. Siltstone	0.1
13. Shale	1.3
12. Siltstone, sideritic cement	0.1
11. Shale	7.0
10. Siltstone, thickness ranges from 0.1 to 0.4 ft	0.2
9. Shale	2.1
8. Siltstone	0.1
7. Shale	1.0

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued	Thickness (feet)
6. Siltstone----------------------------------	0.2
5. Shale; sideritic concretions along several bedding plane horizons-----------------	20.1
4. Siltstone----------------------------------	0.4
3. Shale--------------------------------------	6.2
2. Siltstone, basal grooves 40°-220°---------	1.0
Total Kenwood Siltstone Member----------	44.5
New Providence Shale Member (incomplete):	
1. Shale, greenish gray, to base of exposure (elev 710 ft by altimeter)--------------	7+
Total Borden Formation------------------	196.5+
Base of Borden Formation at elev 510 ft (inferred from structure contours on map, Kepferle, 1972b)	

Buttonmold Knob section

[Section of Kenwood Siltstone and New Providence Shale Members of Borden Formation. Measured on southeast end of Buttonmold Knob, 1.2 miles north of Brooks; top of section at map elev 804 ft in Carter coordinate 3-S-46, in Brooks quadrangle; 1,581,100 ft east, 213,500 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

Mississippian: Borden Formation (incomplete):	Thickness (feet)
Nancy Member (incomplete):	
7. Shale, partly covered to top of hill; may include some siltstone beds of Kenwood--	12
Kenwood Siltstone Member:	
6. Siltstone, massive; obscure laminae in upper 0.3 ft---------------------------	7.5

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

	Thickness (feet)
5. Shale--	3.2
4. Siltstone, obscure flute cast at 170°----	0.6
3. Shale--	4.3
2. Siltstone, top smooth; upper part obscurely laminated; contains trace fossil Chondrites sp.; base not exposed (pl. 1b); Butts, 1915, reports 11.5 ft-	11.5
Total Kenwood Siltstone Member-------	27.1±

New Providence Shale Member:

1. Shale, medium-gray to greenish-gray, clayey, interval mainly covered; base exposed in pit from which fill was taken for Kentucky Turnpike------------	176
Total Borden Formation---------------	215+

Brooks Hill section

[Section of Borden Formation. Measured along Brooks Hill Road from junction with Holsclaw Hill Road at top of Muldraugh escarpment west of Brooks in Carter coordinate 6-S-46 in Brooks quadrangle; top of section at 1,572,300 ft east, 208,500 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

Mississippian:
Harrodsburg Limestone (incomplete):

	Thickness (feet)
25. Residual soil, pale yellowish orange to light brown; contains chert with remains of Spirifer lateralis and pelmatozoans--	14+

Borden Formation:

Muldraugh Member:

24. Siltstone, dolomitic, and dolomite, siliceous and silty, light gray; weathers yellowish gray; wavy bedding laminae; mottled; quartz geodes common; crinoidal limestone in upper 1 ft-----	24

Mississippian--Continued
Borden Formation--Continued
Muldraugh Member--Continued

	Thickness (feet)
23. Limestone, medium-light-gray to moderate-yellowish-brown; silicified in part; crinoidal------------------------------	2
22. Dolomite, silty and siliceous, light-gray with medium-light-gray lamination and mottling; quartz geodes as much as 0.2 ft in diameter common; surface hackly or weathers in spalls------------------	15
Floyds Knob bed:	
21. Mudstone, silty, glauconitic, moderate-yellowish-brown to greenish-gray; glauconite is dusky green to greenish black scattered grains or concentrate in upper 0.1 ft---------------------	1.6
20. Limestone, oolitic, medium- to very coarse-grained fossil fragmental; light olive gray to light brownish gray; fossils include crinoids, brachiopods, bryozoans and microfossils--------------------------------	3.5
Total Floyds Knob bed--------------	5.1
Total Muldraugh Member-------------	46.1
Holtsclaw Siltstone Member:	
19. Siltstone, medium-gray to greenish-gray; weathers the same to yellowish gray; fairly continuous but wavy laminae; massive in fresh exposures; weathers to irregular chips; rare limestone in crinoid-rich lenses and stringers; scattered calcareous concretions are medium gray, dense, and centered around fossil fragments and large orthotetid brachiopods; 0.3-0.5-ft-thick zone of parallel lamination persists for more than 50 ft along the outcrop just above base----	28
18. Shale, silty, medium-dark-gray, slightly calcareous; discontinuous; scattered crinoidal debris------------------------	5

Mississippian--Continued Borden Formation--Continued Holtsclaw Siltstone Member--Continued	Thickness (feet)
17. Siltstone, yellowish-gray to light-olive-gray; limonite-stained in part; scattered iron sulfide nodules; sparse small brachiopods; micaceous-----------	15.8
Total Holtsclaw Siltstone Member-----	48.8
Nancy Member:	
16. Shale, silty, medium- to medium-dark-gray in upper third, medium-light-gray to olive-gray in middle; moderate-yellowish-brown to greenish-gray near base; mica common as silt-size flakes--------------	115
Upper tongue of New Providence Shale Member:	
15. Shale, clayey, silty, greenish-gray; weathers yellowish gray; mainly covered	30
Kenwood Siltstone Member:	
14. Siltstone, basal grooves 60°-240°--------	0.2
13. Shale------------------------------------	16
12. Siltstone, basal grooves 60°-240°--------	0.1
11. Shale------------------------------------	1
10. Siltstone, basal grooves 60°-240°--------	0.2
9. Shale------------------------------------	5
8. Siltstone, basal grooves 65°-245°--------	0.2
7. Shale------------------------------------	1.2
6. Siltstone, basal grooves 45°-225° and 55°-235°; vertical burrow 1 cm wide----	0.4
5. Shale------------------------------------	3
4. Siltstone, basal grooves 70°-250°--------	0.3
3. Shale------------------------------------	5

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

	Thickness (feet)
2. Siltstone, basal grooves at 60°-240°; planar laminae near base; horizontal burrows in upper part------------------	0.6
Total Kenwood Siltstone Member-------	33.2
Lower tongue of New Providence Shale Member:	
1. Shale, clayey, silty, greenish-gray to light-gray; weathers moderate yellowish-brown to light greenish gray; contains scattered ellipsoidal sideritic concretions 0.3 ft to 1 ft in diameter that weather light brown to dark yellowish brown; thin silty laminae contain abundant mica flakes------------	17
Covered. Base of exposure elev 640 ft by altimeter; base of New Providence Shale projected from structure horizon on top of New Albany Shale (Kepferle, 1972b) is at elev 480 ft----------------------	160±
Total lower tongue of New Providence Shale Member------------------------	177±
Total Borden Formation----------------	450

Devonian:
New Albany Shale exposed at base of section; not measured.

Kenlite quarry section
(Appendix B, p. B14)

Bullitt Lick section

[Section of Kenwood Siltstone Member of Borden Formation. Measured along State Highway 44, 0.2 mile northwest of Bullitt Lick Church 3.2 miles west of Shepherdsville; base of section at map elev 540 ft in Carter coordinate 21-S-45 in Valley Station quadrangle; 1,563,100 ft east, 186,400 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

Mississippian:
Borden Formation (incomplete):

	Thickness (feet)
Kenwood Siltstone Member:	
9. Siltstone, single bed; vertical joint set strikes 350°-355°; basal grooves 15°-195°	2.0
8. Shale	1.8
7. Siltstone; vertical joint strikes 355°; basal grooves at 50°-230°	0.7
6. Shale	5.1
5. Siltstone, sole marks at 205°-210°	0.9
4. Shale	2.2
3. Siltstone, no sole marks visible	0.3
2. Shale	7.0
1. Siltstone, horizontal planar laminations	0.1
Total Kenwood Siltstone Member	20.1
Lower tongue of New Providence Shale Member:	
Shale, greenish-gray; thickness inferred from mapping (Kepferle, 1972a)	110±
Section overlying Kenwood not measured in detail; inferred during mapping are the following thickness in ascending order above the Kenwood: Upper tongue of New Providence Shale Member, 50 ft; Nancy Member, 100 ft; Holtsclaw Siltstone Member, 120 ft; Muldraugh Member, 30 ft;	
Total Borden Formation, inferred	430±

Cane Hollow section

[Section of Kenwood Siltstone Member of Borden Formation. Measured up north side of ravine draining into Cane Hollow Branch of Long Lick, about 2.1 miles northeast of Clermont, 5.2 air miles east-southeast of Shepherdsville. Top of section at topographic contour elev 880 ft in Carter coordinate 18-R-47 in the Samuels quadrangle; 1,604,700 ft east, 164,300 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member:	
37. Shale and scattered blocks of siltstone less than a foot thick in float; mostly covered to top of hill---------	30
36. Siltstone--------------------------------	1.2
35. Shale, mostly covered------------------	1.8
34. Siltstone; two partings split bed in thirds--------------------------------	0.6
33. Shale----------------------------------	0.2
32. Siltstone, vertical burrow in upper part	0.9
31. Shale----------------------------------	0.7
30. Siltstone, basal grooves 40°-220°, 50°-230°----------------------------------	1.8
29. Shale----------------------------------	0.2
28. Siltstone--------------------------------	3.0
27. Shale----------------------------------	0.7
26. Siltstone, vertical burrow in upper foot	5.5
25. Shaly siltstone------------------------	1.0
24. Siltstone, vertical burrow in upper half	2.3
23. Shaly siltstone, less resistant than beds above or beneath----------------	1.8

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
22.	Siltstone----------------------------------	1.3
21.	Siltstone, truncated laterally by overlying bed------------------------------	0.6
20.	Siltstone----------------------------------	2.0
19.	Shale--------------------------------------	0.3
18.	Siltstone----------------------------------	0.2
17.	Shale--------------------------------------	0.3
16.	Siltstone----------------------------------	1.5
15.	Shale--------------------------------------	0.8
14.	Siltstone, partings at 0.4 and 1 ft below top; photo of underside (pl. 9, bottom)	1.9
13.	Shale parting	
12.	Siltstone, penetrated by vertical burrow-	0.8
11.	Siltstone, inclined burrow---------------	1.7
10.	Siltstone, limonite-cemented in top------	1.7
9.	Siltstone, limonite-cemented in basal 0.4 ft----------------------------------	1.1
8.	Siltstone, vertical burrow in top third--	3.6
7.	Siltstone, near-vertical burrows---------	0.8
6.	Shale--------------------------------------	0.1
5.	Siltstone, vertical burrows in top 0.5 ft	4.7
4.	Shale--------------------------------------	0.2
3.	Siltstone, limonite-cemented zone from weathered sideritic concretions in middle part of bed (top photograph, pl. 7)	3.6
2.	Shale--------------------------------------	1.0

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued	Thickness (feet)
1. Siltstone, base not exposed--------------	1+
Total Kenwood Siltstone Member---------	80.9+
New Providence Shale Member:	
Not measured; thickness inferred from mapping (Kepferle, 1969)----------------------------	120±
Total Borden Formation--------------------	200+

Remarks: Kenwood Siltstone beds in this exposure dip northeast as much as 10°; beds tend to merge down dip, characteristic of type III channel fill (fig. 16).

Firetower Hill section

[Section of Kenwood Siltstone and New Providence Shale Members of the Borden Formation. Measured along road leading to Lookout tower in Bernheim Forest; top of section in parking lot for tower, about 3 miles by road south of Clermont, 7.5 air miles southeast of Shepherdsville in Carter coordinate 3-Q-47, in the Shepherdsville quadrangle; 1,602,600 ft east, 139,900 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

Mississippian: Borden Formation (incomplete):	Thickness (feet)
Upper tongue of New Providence Shale Member (incomplete):	
49. Shale, clayey and silty, weathered to yellowish gray, mostly covered from parking lot (elev 865 by altimeter)---	70±
Kenwood Siltstone Member:	
48. Siltstone--------------------------------	0.2
47. Shale, partly covered-------------------	2
46. Siltstone, limonite cement in middle; zone of ripple laminae less than 0.1 ft thick, planar laminae in basal 0.3ft	0.8

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
45.	Shale, silty----------------------------	2.6
44.	Siltstone, limonite cement in middle----	1.0
43.	Shale-----------------------------------	0.5
42.	Siltstone-------------------------------	0.1
41.	Shale-----------------------------------	10
40.	Siltstone, limonite cement; vertical burrows, Chondrites; basal grooves at 40°-220°; ripple laminae in basal part of bed, 0.1 ft above base.------------	1.0
39.	Shale-----------------------------------	0.2
38.	Siltstone, shale seam at base-----------	0.6
37.	Siltstone; Zoophycos ; flute 225°-------	0.5
36.	Shale-----------------------------------	3
35.	Siltstone, basal grooves 40°-220°-------	0.2
34.	Shale-----------------------------------	4
33.	Siltstone-------------------------------	0.7
32.	Shale-----------------------------------	1.5
31.	Siltstone-------------------------------	0.4
30.	Shale-----------------------------------	1.0
29.	Siltstone, basal grooves at 35°-215°; top contains horizontal burrows-------	0.4
28.	Shale-----------------------------------	1.7
27.	Siltstone, shaly, laminated base; basal grooves 40°-220°---------------------	0.6
26.	Shale-----------------------------------	3.0
25.	Siltstone; vertical burrows; limonite cement in middle; flame structure in top	1.0

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued	Thickness (feet)
24. Shale------------------------------------	0.7
23. Siltstone, *Chondrites* in upper part; basal grooves at 45°-225° and 65°-245°	0.5
22. Shale------------------------------------	0.5
21. Siltstone, basal grooves 65°-245°-------	0.5
20. Shale, contains 0.1-ft silty bed 0.2 ft below top----------------------------	5
19. Siltstone, top of bundle; may be two beds as basal 0.2 ft is laminated, overlain by *Cosmorhaphe*?-bearing shaly zone 0.1 ft thick; entire bed penetrated by vertical burrow--------------------------	0.5
18. Shale------------------------------------	0.5
17. Siltstone; contains flame structure with divergent directionals; *Chondrites* in upper part; basal furrow flute marks at 245° (pl. 11, top)----------------	0.6
16. Shale------------------------------------	0.1
15. Siltstone, sideritic cement near top; *Chondrites* in upper part; convolute bedding lies between planar bedding lamination---------------------------	1.1
14. Shale------------------------------------	0.1
13. Siltstone, burrowed, with *Zoophycos*-like burrow in cross-section (pl. 8a)------	0.4
12. Shale------------------------------------	0.2
11. Siltstone, load casts strike 155° (normal to current?)---------------------	0.6
10. Shale------------------------------------	0.2
9. Siltstone, massive; *Chondrites*, *Cosmorhaphe* 1 mm wide in upper part; groove 65°-245° in base----------------------------	0.5

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued	Thickness (feet)
8. Siltstone, separated from overlying bed by thin shale parting; grooves at 250°; planar lamination common; base may contain ripple lamination--------------	1.1
7. Shale------------------------------------	0.4
6. Siltstone; vertical burrows in upper 1.2 ft; contains *Chondrites* sp.; upper suf-face shows stripe-like horizontal bur-rows; load-casts in base of upper part, just below zone of sideritic concretions	2.2
5. Shale------------------------------------	0.3
4. Siltstone, iron-cemented in upper half; basal part planar laminated; sole marks at 220° and 250°-----------------------	1.2
3. Shale------------------------------------	0.2
2. Siltstone, upper 1.5 ft appears amalgam-ated with lower, thicker bed; interference ripples on top; laminated bedding lies on massive bedding (pl. 5b); *Chondrites* sp. common upper part; iron cement 1.5-2.2 ft below top; base not exposed -------------	6.5+
Total Kenwood Siltstone Member----------	60.9+
Lower tongue of New Providence Shale Member:	
1. Shale, partly covered and slumped to top of underlying unit in Wildcat Hollow, below------------------------------------	88±
Total Borden Formation----------------	218+
Devonian: New Albany Shale, not measured.	

Crooked Creek section

[Section of Kenwood Siltstone Member of Borden Formation. Measured at head of Rocky Hollow 0.1 mile west of jeep trail 1.2 miles from junction near Lookout tower in Bernheim Forest, in Carter coordinate 7-Q-47 in Shepherdsville quadrangle; 1,599,700 ft east, 146,400 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky. The basal Kenwood in this exposure is representative of a type II channel-fill (fig. 16)]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Upper tongue of New Providence Shale Member (incomplete):	
9. Covered, probably shale to top of hill (map elev 823 ft)	35+
Kenwood Siltstone Member:	
8. Siltstone and shale, mostly covered, from highest siltstone float block on hill	15
7. Siltstone, beds mostly less than 1 ft thick and interbedded with thin shale beds; poorly exposed	43
6. Siltstone, in single bed, top covered	18.5+
5. Covered, probably shale	1
4. Siltstone	9
3. Covered, probably shale	3.5
2. Siltstone, single bed, bedding obscure, top covered	20+
Total Kenwood Siltstone Member	110
Lower tongue of New Providence Shale Member:	
1. Covered, probably shale	38
Total Borden Formation	183+

Devonian:
New Albany Shale; exposed in creek; not measured.

Iron Furnace section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of Borden Formation. Measured up bare nose between power line and pipe line trace on north side of Crooked Creek 1.3 miles east of Belmont by way of State Highways 251 and 61; private road leading to section joins State Highway 61 south of Shepherdsville 7.1 miles; base of section is in hog lot in Carter coordinate 9-Q-46 in the Shepherdsville quadrangle; 1,582,900 ft east, 146,000 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member (incomplete):	
8. Siltstone and shale to top of nose; siltstone beds mainly less than 0.3 ft thick-	10
7. Shale--	16
6. Siltstone, basal grooves 110°-290°; <u>Zoophycos</u>-----------------------------------	0.3
5. Shale--	1.7
4. Siltstone; horizontal straight burrow 0.1 ft wide in top surface-------------------	1.2
3. Siltstone and shale, not measured in detail	10.8
Total Kenwood Siltstone Member-----------	40+
Lower tongue of New Providence Shale Member:	
2. Shale, greenish-gray; sideritic concretions near top----------------------------------	50
Total Borden Formation-----------------	90+
Devonian:	
New Albany Shale (incomplete):	
1. Shale, brownish-black, fissile-weathering, base not exposed-------------------------	30+

Elev 550 ft by altimeter at top of New Albany Shale.

State Highway 61 section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of Borden Formation. Measured up roadcut on west side of State Highway 61; 7.7 miles south of Shepherdsville in Carter coordinate 8-Q-46 in Shepherdsville quadrangle; 1,581,500 ft east, 143,400 ft north, Kentucky coordinate system, north zone, Bullitt County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member:	
18. Siltstone; limonite-cement in middle of bed; penetrated by vertical burrows; some horizontal burrows; base shows browsing casts. Overlain by 4 ft of shale to covered zone----------------	0.5
17. Shale, greenish-gray, with sideritic concretions in layers 2 ft to 4 ft apart commencing 9 ft below top-------	27.3
16. Siltstone; upper part of bed contains wide straight horizontal burrows, narrow _Chondrites_-like burrows, and meandering _Scalarituba missouriensis_--	0.3
15. Shale------------------------------------	0.5
14. Siltstone, laminated; hint of low-angle cross-laminae near top; grooves at 85°-265° (sample SH-2T, -2B)--------------	0.7
13. Shale------------------------------------	0.9
12. Siltstone, basal grooves 70°-250°-------	0.6
11. Shale; nodule zone 3.3 ft below top-----	4.8
10. Siltstone; top, burrowed; base, smooth and planar----------------------------	0.2
9. Shale------------------------------------	0.4
8. Siltstone; limonite cemented in middle; basal grooves at40°-220° to 55°-235°; casts of small browsing traces; base pyritic------------------------------	0.4

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

	Thickness (feet)
7. Shale, greenish-gray, with sideritic concretions in layers 2 ft, 8.5 ft and 12 ft below top------------------------	13.0
6. Siltstone, acts as a center for sideritic concretionary layer (bottom, pl. 7)----	0.1
5. Shale-------------------------------------	1.4
4. Siltstone, laminated bedding at top (samples SH-1-T, -M, and -B)-----------	0.6
Total Kenwood Siltstone Member-------	51.7
Lower tongue of New Providence Shale Member:	
3. Shale, greenish-gray; zones of siderite concretions at base and 4 ft, 7 ft, 12 ft, and 17 ft below top-------------	22.4
2. Shale, clayey, light-greenish-gray; zone of phosphatic nodules in basal foot----	35
Total lower tongue of New Providence Shale Member-----------------------	57.4
Total Borden Formation---------------	109.1+

Devonian:
New Albany Shale (incomplete):

1. Shale, brownish-black; exposed in ravine north of roadcut, not measured

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
3.	Shale--	0.4
2.	Siltstone, parting 1.4 ft below top------	3.1
	Total Kenwood Siltstone Member---------	11.1+

New Providence Shale Member (incomplete):

1.	Shale, greenish-gray, complete section not measured----------------------------	5+
	Total Borden Formation-----------------	16.1+

Indian Grave Ridge section

[Section of the Kenwood Siltstone Member and the lower tongue of the New Providence Shale Member of the Borden Formation. Measured along secondary road leading into Knobs State Forest, 013 mile north of U.S. Highway 62 and 1.6 miles west of Cravens, in Carter coordinate 6-P-48 in Cravens quadrangle; top of section at top of nose (topographic contour elev 780+ ft); 2,050,700 ft east, 539,600 ft north, Kentucky coordinate system, south zone, Nelson County, Kyl]

Mississippian:
Borden Formation (incomplete):

Kenwood Siltstone Member:

		Thickness (feet)
79.	Siltstone, to top of hill----------------	0.2
78.	Shale, silty------------------------------	1.9
77.	Siltstone----------------------------------	0.2
76.	Shale; includes non-resistant silty layers	3.4
75.	Siltstone; limonite cement concentrated in middle of bed coincides with brachiopod-rich layer; base of bed shows casts of spines which may support idea of transport emplacement of brachiopods; trace fossils include straight horizontal cephalopod? burrows in top, <u>Chondrites</u> and vertical burrows; basal grooves 205°	1.2

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued		Thickness (feet)
74.	Shale--	0.6
73.	Siltstone, abundant borings on upper surface; shale seam 0.1 ft above base--	0.7
72.	Shale--	0.3
71.	Siltstone, basal grooves at 15°-195°-----	0.2
70.	Shale--	0.1
69.	Siltstone------------------------------------	0.1
68.	Shale--	0.1
67.	Siltstone; prod cast 190°; clay-filled burrows abundant in top----------------	0.2
66.	Shale--	0.1
65.	Siltstone; *Chondrites* in upper part; basal grooves 30°-210°----------------	0.4
64.	Shale--	0.1
63.	Siltstone, weakly indurated-------------	0.1
62.	Shale--	0.1
61.	Siltstone------------------------------------	0.2
60.	Shale--	0.1
59.	Siltstone; clayey in top; heavily limonite-stained in base-------------------	0.7
58.	Shale--	0.4
57.	Siltstone------------------------------------	0.8
56.	Shale--	0.1
55.	Siltstone, low flute 220°---------------	1.0
54.	Shale--	0.1
53.	Siltstone------------------------------------	0.7

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued		Thickness (feet)
52.	Shale---------------------------------------	0.1
51.	Siltstone in three ledges, partings 0.5 ft below top and 0.8 ft above base----	2.0
50.	Shale, thin seam	
49.	Siltstone, parting 0.9 ft above base----	3.0
48.	Shale---------------------------------------	0.2
47.	Siltstone, weakly indurated-------------	0.2
46.	Shale---------------------------------------	0.3
45.	Siltstone, basal grooves 185°-200°------	1.4
44.	Shale---------------------------------------	0.4
43.	Siltstone, weakly indurated-------------	0.2
42.	Shale---------------------------------------	0.4
41.	Siltstone; vertical burrows with crescent-shaped outline-----------------------	1.5
40.	Shale---------------------------------------	0.2
39.	Siltstone, weakly resistant, smooth base	0.5
38.	Shale---------------------------------------	0.2
37.	Siltstone, abundant burrows-------------	0.9
36.	Shale---------------------------------------	0.1
35.	Siltstone, basal grooves 10° and 335°---	0.5
34.	Shale---------------------------------------	0.3
33.	Siltstone, vertical burrow through bed--	0.3
32.	Shale---------------------------------------	0.1
31.	Siltstone, abundant <u>Chondrites</u>----------	0.5
30.	Shale---------------------------------------	0.1

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
29.	Siltstone------------------------------------	2.2
28.	Shale--	0.2
27.	Siltstone; shale parting at base and 0.8 ft below top; abundant Scalarituba sp. and Cosmorhaphe sp. in upper part-----	1.9
26.	Siltstone------------------------------------	0.1
25.	Shale parting	
24.	Siltstone, limonite-stained-------------	0.5
23.	Shale--	0.1
22.	Siltstone------------------------------------	0.8
21.	Shale--	0.3
20.	Siltstone, limonite-stained at base-----	1.5
19.	Shale--	0.1
18.	Siltstone------------------------------------	0.7
17.	Shale--	0.2
16.	Siltstone, clayey in upper 0.9, heavily limonite-stained in basal 0.3 ft; basal grooves 15°-195°----------------	1.7
15.	Shale--	0.1
14.	Siltstone------------------------------------	0.1
13.	Shale--	0.1
12.	Siltstone------------------------------------	1.2
11.	Shale, contains some non-indurated silty layers----------------------------------	0.2
10.	Siltstone, bedding poorly defined-------	3.6
9.	Shale, like 11, above-------------------	1.8

State Highway 733 section

[Section of Kenwood Siltstone Member of Borden Formation. Measured along dirt road 0.2 mile east of State Highway 733, southeast 2.7 miles from junction with State Highway 61 north of Lebanon Junction, in Carter coordinate 21-Q-46 in Lebanon Junction quadrangle; 1,589,200 ft east, 128,400 ft north, Kentucky coordinate system, north zone, Bullitt County, Kentucky]

Mississippian:
Borden Formation (incomplete):

Kenwood Siltstone Member:

		Thickness (feet)
21.	Shale, partly covered, to top of hill---	1.0+
20.	Siltstone----------------------------------	0.2
19.	Shale--	2.0
18.	Siltstone----------------------------------	0.7
17.	Shale--	0.3
16.	Siltstone----------------------------------	0.1
15.	Shale--	0.5
14.	Siltstone----------------------------------	0.2
13.	Shale--	0.2
12.	Siltstone----------------------------------	0.4
11.	Shale--	0.1
10.	Siltstone----------------------------------	0.2
9.	Shale--	0.1
8.	Siltstone----------------------------------	0.6
7.	Shale--	0.1
6.	Siltstone----------------------------------	0.2
5.	Shale--	0.1
4.	Siltstone----------------------------------	0.6

Mississippian--Continued
Borden Formation--Continued
Kenwood Siltstone Member--Continued

		Thickness (feet)
8.	Siltstone	2.0
7.	Shale, poorly exposed, slumped	1.1
6.	Siltstone	1.8
5.	Shale	0.1
4.	Siltstone, basal grooves 10°-190°	1.9
3.	Shale, poorly exposed	1.1
2.	Siltstone	2.4
	Total Kenwood Siltstone Member:	55.4
	Lower tongue of New Providence Shale Member:	
1.	Shale, clayey, greenish-gray, partly covered	74
	Total Borden Formation	129.4+

Devonian:
New Albany Shale (not measured)

Boston section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of Borden Formation. Measured along U.S. Highway 62 west of railroad crossing in Boston, in Carter coordinate 11-P-46 in Lebanon Junction quadrangle; top of section 2,021,500 ft east, 528,200 ft north, Kentucky coordinate system, south zone, Nelson County, Ky.]

Mississippian:
Borden Formation (incomplete):

Kenwood Siltstone Member:

		Thickness (feet)
16.	Siltstone, limonite-stained in middle of bed; flute cast 210°; overlain by 5-ft thick covered zone, north side of road	1.6

Mississippian--Continued Borden Formation--Continued Kenwood Siltstone Member--Continued	Thickness (feet)
15. Shale	0.2
14. Siltstone, shaly; poorly exposed	0.5
13. Shale	0.2
12. Siltstone; vertical burrows; horizontal burrows in top part of bed	0.5
11. Shale	0.2
10. Siltstone, laminated in top 0.2 ft; burrow on upper surface, in top 0.1 ft	0.7
9. Shale	0.3
8. Siltstone; 0.1-ft-thick zone of ripple bedding 0.5 ft above base, foresets dip toward 195°; basal grooves range from 200° to 215°	1.8
7. Shale, clayey, planar laminated	0.1
6. Shale, silty, laminated	0.2
5. Siltstone, planar laminated	0.2
4. Siltstone; massive bed; top 0.1 ft heavily limonite-cemented; sideritic zone 1.3 ft above base; basal grooves with drag mark 250°; basal 0.1 ft contains abundant clay-filled burrows from which smaller feeders radiate	6.3
3. Shale	0.3
2. Siltstone, planar base, ripple casts, crests strike 270°	1.0
Total Kenwood Siltstone Member	14.1
Lower tongue of New Providence Shale Member:	
1. Shale, greenish-gray, clayey; phosphate-nodule zone at base	23.6
Total Borden Formation	37.7+

Devonian New Albany Shale at base, not measured.

Beech Fork section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of Borden Formation. Measured in cut on west side of State Highway 52, 0.1 mile south of Beech Fork, 1 mile south of junction with U.S. Highway 62 west of Boston, in Carter coordinate 21-P-46 in Lebanon Junction quadrangle; top of section 2,020,700 ft east, 520,400 ft north, Kentucky coordinate system, south zone, Nelson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member:	
9. Siltstone, float block from soil zone-----	0.4
8. Shale, mixed with soil, partly covered----	2
7. Siltstone; horizontal burrows 2 cm wide in top; limonite cement in middle; basal grooves at 245°-------------------------	0.8
6. Shale--	0.2
5. Siltstone; *Chondrites* in top; base smooth except for rare groove 75°-255°---------	0.6
4. Shale, silty--------------------------------	0.6
3. Siltstone; faint shallow small burrows in upper 0.4 ft; iron-stained base obliterates sole marks-------------------------	1.3
Total Kenwood Siltstone Member--------	5.9±
Lower tongue of New Providence Shale Member:	
2. Shale, clayey, greenish-gray; brownish-gray phosphatic nodules in basal 1 ft---	26.7
Total Borden Formation----------------	32.6+
Devonian:	
New Albany Shale (incomplete):	
1. Shale, brownish-black; cut by quartzose geode dike-like body as much as 0.2 ft thick on north end of exposure-----------	5+

Rolling Fork section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of Borden Formation. Measured on south face of borrow pit above pond south of Bluegrass Parkway near bend in Rolling Fork; the farm entrance to the pond is 2.7 miles southeast of U.S. Highway 62 and 8.8 miles northwest of New Haven, Ky., on State Highway 583 in Carter coordinate 2-0-46 in Nelsonville quadrangle; 2,018,700 ft east, 511,100 ft north, Kentucky coordinate system, south zone, Hardin County, Ky. (pl. 1c)]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member:	
8. Siltstone; trace of planar lamination; limonite stain at base from weathered sideritic concretion zone----------------	3.6
7. Siltstone; obscure planar lamination------	3.6
6. Shale, silty, laminated-------------------	0.1
5. Siltstone, single massive bed; basal 0.1 ft cemented in part by iron sulfide that weathers to limonite; no sole mark on large underside of slumped block; ripple laminae in upper 0.4 ft; upper 0.5 ft contains abundant <u>Chondrites</u>-like burrows; unit thins across pond to 2.2 ft in thickness---------------------	5.4
Total Kenwood Siltstone Member----------	12.7
Lower tongue of New Providence Shale Member:	
4. Shale, clayey, greenish-gray to olive-gray	11.2
3. Shale, clayey, medium brownish gray-------	0.3
2. Shale, clayey, as in 4. above, dusky yellow green near base; abundant phosphatic pebbles abundant in zone 1 ft above base; underlain by glauconitic shale-----------	4.5
Total lower tongue of New Providence Shale Member--------------------------	16.0
Total Borden Formation-----------------	28.7+

Devonian:
New Albany Shale (incomplete):

	Thickness (feet)
1. Shale, black to grayish black, to pond level; base not exposed-------------------	3+

Blue Gap section

[Section of the Kenwood Siltstone and New Providence Shale Members of the Borden Formation. Measured along ravine west of U.S. Highway 31-E at Blue Gap 2.3 miles northeast of New Haven in Carter coordinate 17-0-48 in the New Haven quadrangle; 2,053,200 ft east, 493,100 ft north, Kentucky coordinate system, south zone, Nelson County, Ky.]

Mississippian:
Borden Formation (incomplete):

	Thickness (feet)
Upper tongue of New Providence Shale Member:	
5. Shale, weathers light greenish gray; to top of hill to west--------------------	76+
Kenwood Siltstone Member:	
4. Siltstone---------------------------------	0.15
3. Shale-------------------------------------	0.15
2. Siltstone; basal groove and low flute cast 215°; *Chondrites* sp. common; bed penetrated by crescentic vertical burrow; some calcitic, sideritic, cement; planar internal bedding laminae----------------	0.4
Total Kenwood Siltstone Member--------	0.7
Lower tongue of New Providence Shale Member:	
1. Shale, clayey, greenish-gray; zone of phosphatic nodules in basal foot-------	42
Total Borden Formation---------------	117+

Devonian:
New Albany Shale (not measured; top at elev 520 ft by altimeter)

Pine Knob section

[Section of Kenwood Siltstone Member and lower tongue of New Providence Shale Member of the Borden Formation. Measured on south side of Pine Lick Knob, the top of which is 0.1 mile east of State Highway 46, 3.8 miles northwest of Holy Cross in Carter coordinate 14-0-49 in the Loretto quadrangle; 2,077,800 ft east, 502,600 ft north, Kentucky coordinate system, south zone, Nelson County, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Kenwood Siltstone Member (incomplete?):	
6. Siltstone, yellowish-gray; single bed; top contains abundant horizontal burrows; some vertical burrows; planar bedding lamination; base not exposed-------------	2±
5. Shale, mostly covered with slumped blocks from overlying bed-----------------------	8±
4. Siltstone, slightly slumped; vertical burrows common; basal grooves in two sets, not measured because of slumped nature---	0.5
Total Kenwood Siltstone Member---------	10.5
Lower tongue of New Providence Shale Member:	
3. Shale, clayey, greenish-gray, silty; zone of sideritic concretions at base---------	21
2. Shale, clayey, as above; zone of spherical phosphatic nodules 2-3 cm in diameter at base-------------------------------------	38
1. Shale, less silty than above; zone of phosphate nodules at base----------------	42
Total New Providence Shale Member------	101
Devonian:	
New Albany Shale (not measured)	

Rowans Knob section

[Reconnaissance section of Borden Formation on south side of Rohan Knob. Triangulation point on north end of knob is 0.8 mile north of Holy Cross in Carter coordinate 18-0-49 in Loretto quadrangle; 2,086,600 ft east, 492,600 ft north, Kentucky coordinate system, south zone, Nelson-Marion County line, Ky.]

	Thickness (feet)
Mississippian:	
Borden Formation:	
Muldraugh Member:	
11. Siltstone, dolomitic, and silty dolomite to top of hill, upper part covered----	45±
Floyds Knob bed:	
10. Glauconite-rich dolomite--------------	0.2
9. Shale, olive-gray---------------------	3.0
8. Limestone, dark-yellowish-brown to medium-gray, fossil fragmental, glauconitic; fossils include bryozoans, brachiopods, and corals; crossbedding dips 20° toward 220°; in massive ledge--------------------	3.2
7. Shale--------------------------------	0.1
6. Limestone, like 8 above---------------	0.7
5. Shale, silty, calcareous, cross-bedded	0.2
4. Limestone, like 8 above---------------	1.0
Total Floyds Knob bed---------------	8.4
Total Muldraugh Member--------------	53±
Nancy Member:	
3. Shale, silty, calcareous----------------	16.4
2. Siltstone and silty shale (by altimeter)-	66
Total Nancy Member--------------------	82

Mississippian--Continued	
Borden Formation--Continued	Thickness (feet)
New Providence Shale Member:	
1. Shale, greenish-gray, increasingly clayey towards the base; sideritic concretions 142 ft below silty ledges at base of Nancy Member----------------------------	208
Total Borden Formation---------------	343±

Devonian:
New Albany Shale (exposures in road not measured)

PLATES
(Localities shown on figure 7)

Plate 1. Thick beds in the Kenwood Siltstone Member.
a. Channel fill, type III, Cane Hollow, loc. N.
b. Channel fill, type II, Buttonmold Knob, loc. J.
c. Channel fill, type II, Rolling Fork, loc. W.

Plate 2. Photomicrographs of the Kenwood siltstone. Silt grains in a pyrite matrix: Kenlite quarry, loc. L.
a. Feldspar grain shows overgrowth;
b. Overgrowth accentuated by differential extinction (sample BR-1-C).

Clay filled burrows.
c. Siltstone bed on Kenwood Hill, loc. E, sample LW-1-40.
d. Siltstone bed in Shepherdsville quadrangle, loc. R, sample SH-2T.

Pyrite laminae in plain (e.) and polarized (f.) light; calcite matrix, loc. L, sample BR-1-B.

Plate 3. Photomicrograph of basal contact, bed 2, Kenwood Hill, loc. E, sample LW-1-20.

Plate 4. Planar lamination in siltstone of the Kenwood.
Top, X-radiograph of thin slab, loc. E, sample LW-1-20.
Bottom, bed beneath overhand along Crooked Creek, loc. P-Q.

Plate 5. Internal bedding sequences in siltstone beds along Firetower Hill road, loc. O.
a. Convolute laminae.
b. Massive bedding overlain by laminated bedding in 1.2 ft. wiltstone bed.

Plate 6. Kenwood siltstone bed along Pleiss Hollow, loc. B.
Basal planar lamination overlain in turn by layer of starved-ripple lamination, planar and convolute lamination, a second layer of starved-ripple lamination, more planar lamination, and, at the top, a zone of climbing-ripple laminae.

Plate 7. Sideritic "ironstone" concretions in Kenwood Siltstone Member.
Top, concretionary zone in middle of massive-bedded siltstone, loc. N.
Bottom, concretion centered on a thin siltstone bed along State Highway 61, loc. R.

Plates - Continued

Plate 8. Trace Fossils.

a. Nereites-like pattern in vertical cross-section of bed; possibly related to Zoophycos sp., as in c. below. Loc. O.
b. Zoophycos-like form with crescentic burrow, loc. R.
c. Larger Zoophycos-like form, loc. O.

Plate 9. Sole marks on the siltstone beds of the Kenwood.
Top, two sets of grooves and a sinuous trace fossil, possibly Planolites sp., loc. N.
Bottom, load casts with bulbous ends pointing down-current as established from nearby chevrons associated with groove casts, loc. N.

Plate 10. Trace fossil Chondrites sp.
Top, in a vertical section (loc. O) associated with flame structure along a possible amalgamated contact above which is massive bedding and below which is planar-laminated bedding.
Bottom, along bedding-plane surface, loc. R.

Plate 11. Trace fossils of Pascichnia affinities, loc. Q.

a. Lophoctenium sp.
b. Unidentified.
c. Unidentified, some appear to have formed following deposition of the overlying bed.

Plate 12. Trace fossils of Fodinichnia affinities.
Top, Scalarituba missouriensis Weller with smaller Cosmorhaphe? sp. on upper surface of siltstone bed along St. Andrews Church Road, loc. D.
Base, orthoconic cephalopod? trails, loc. N.

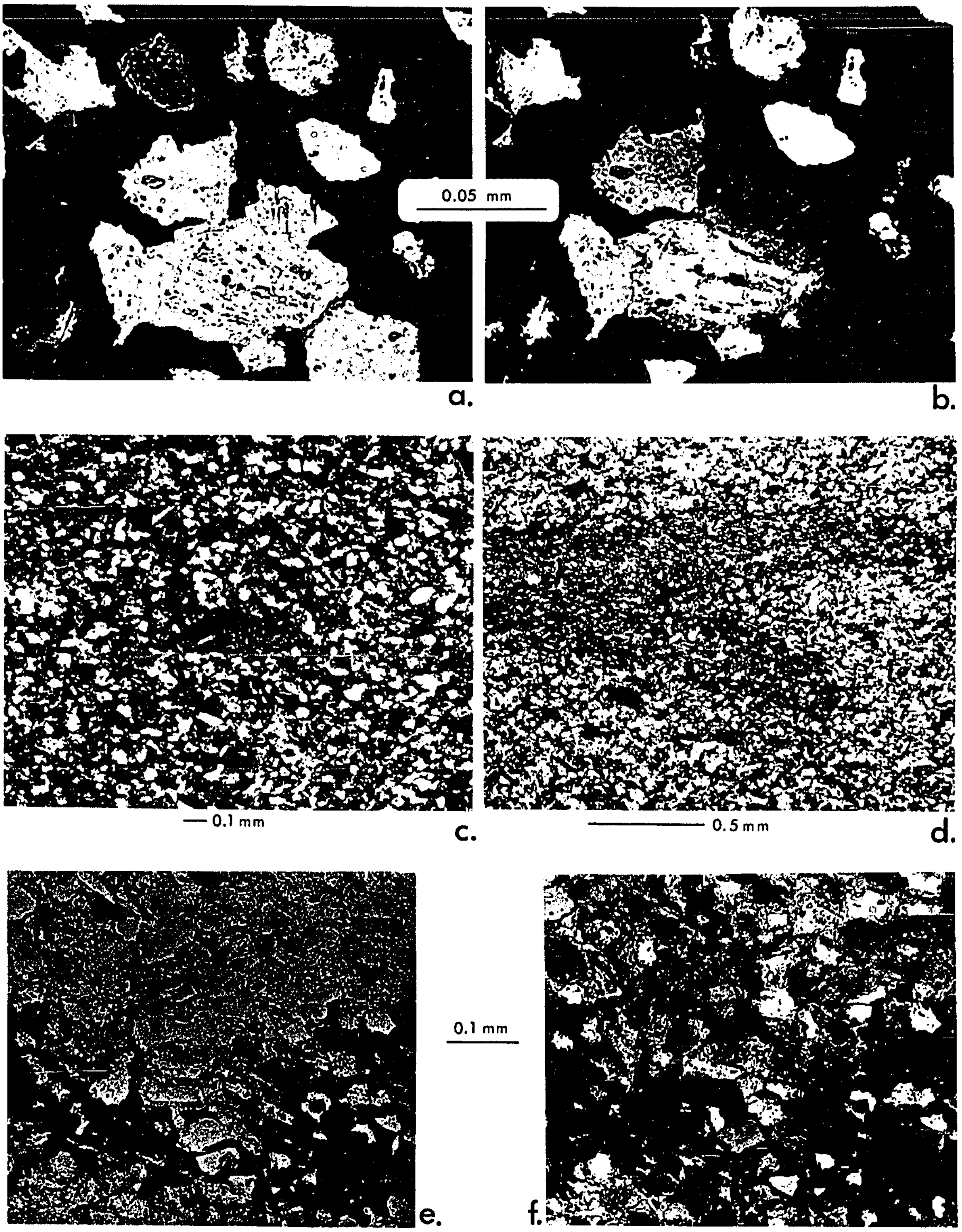
Plate 1

a.

b.

c.

Plate 2



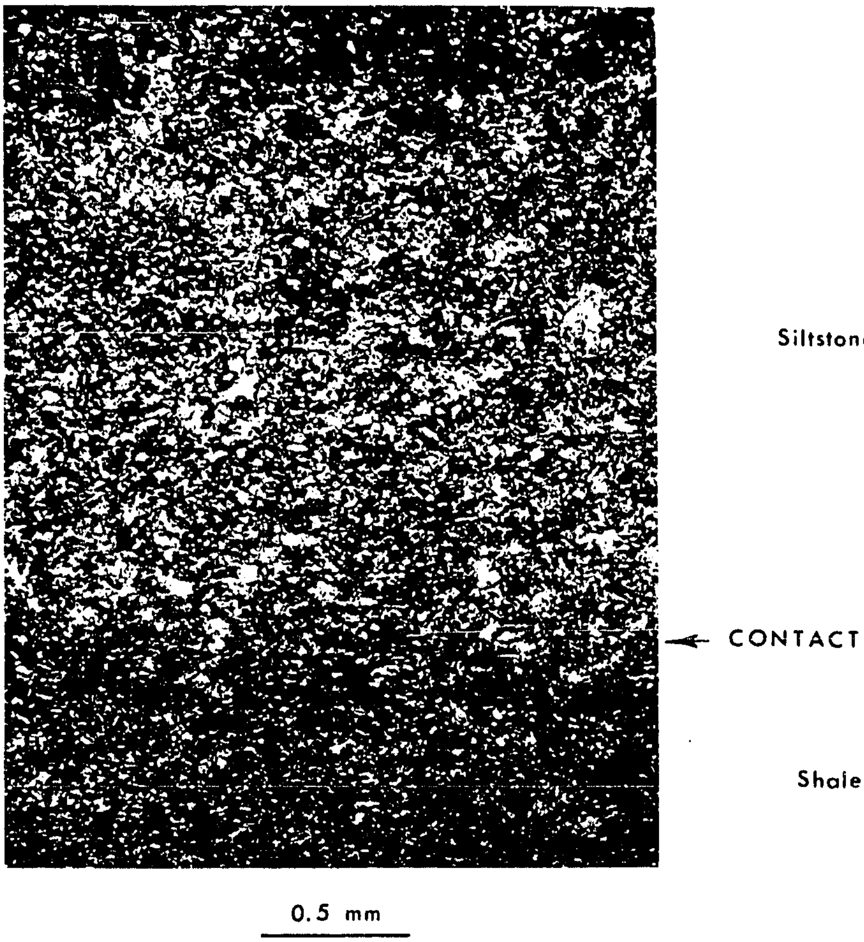
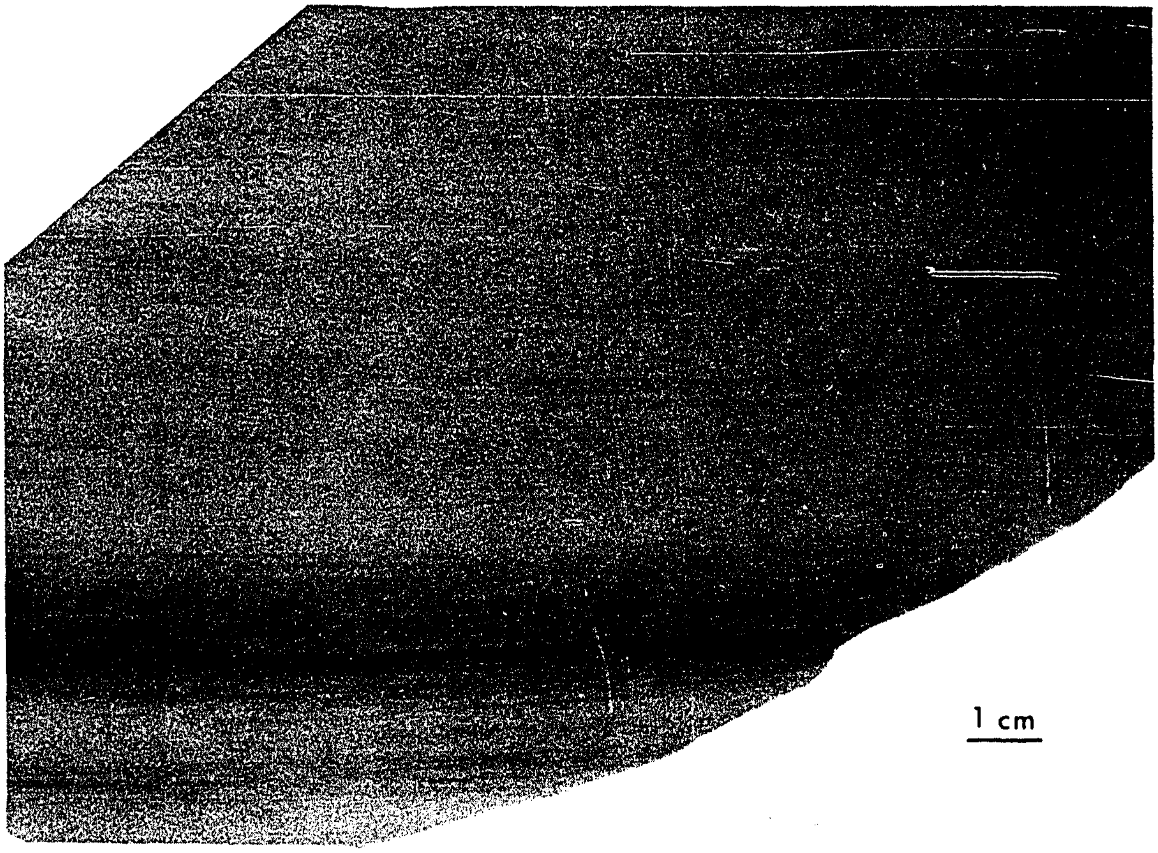

Siltstone
CONTACT
Shale
0.5 mm

Plate 4



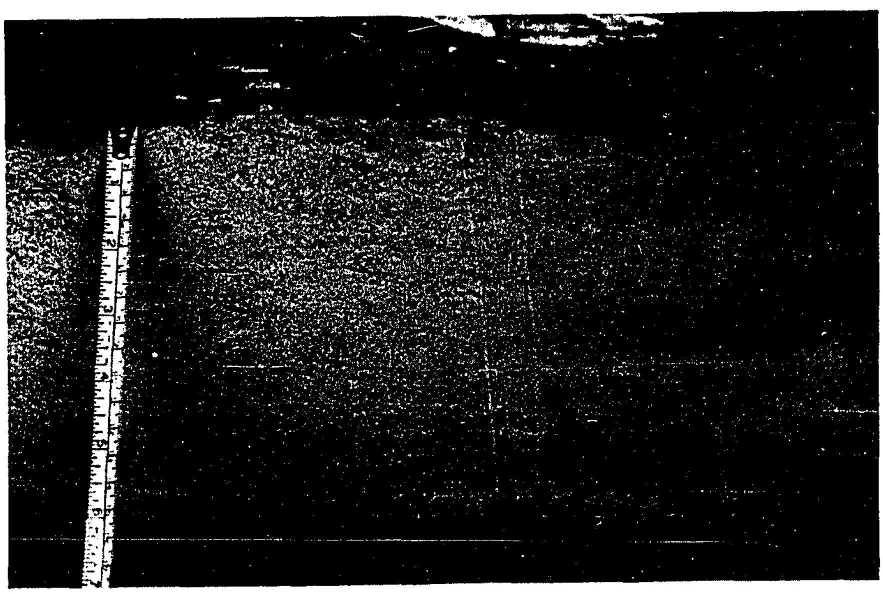
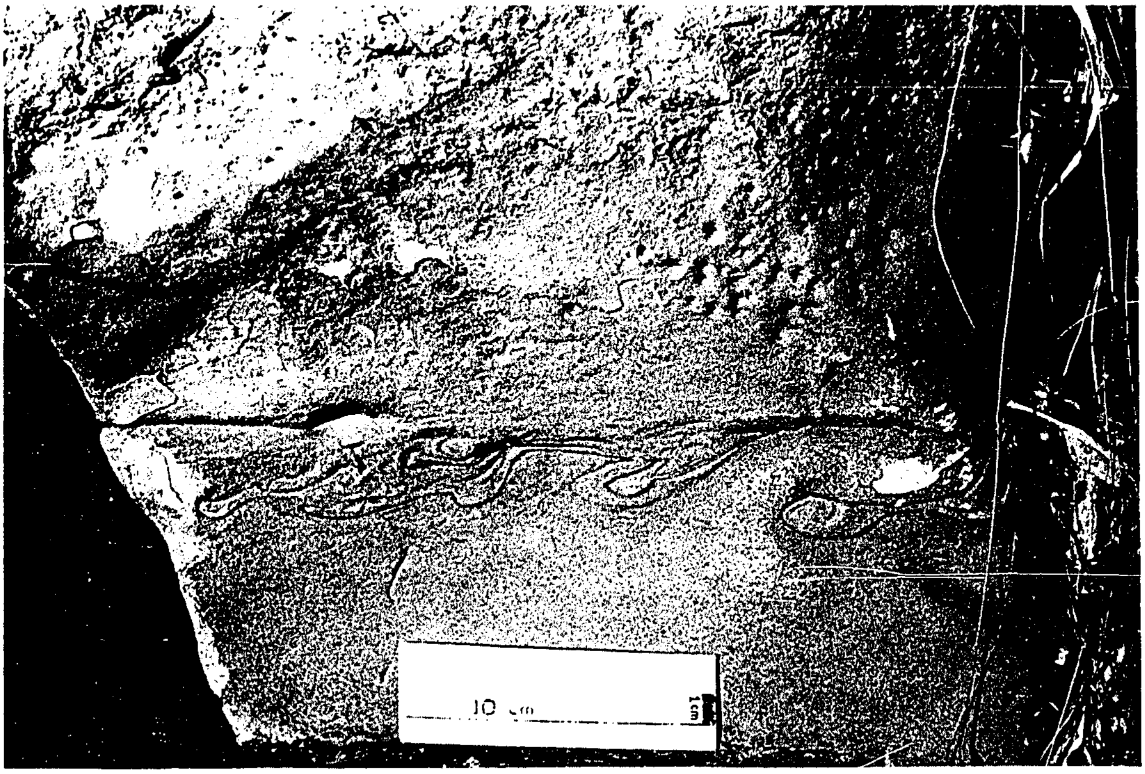


Plate 5



a.

b.

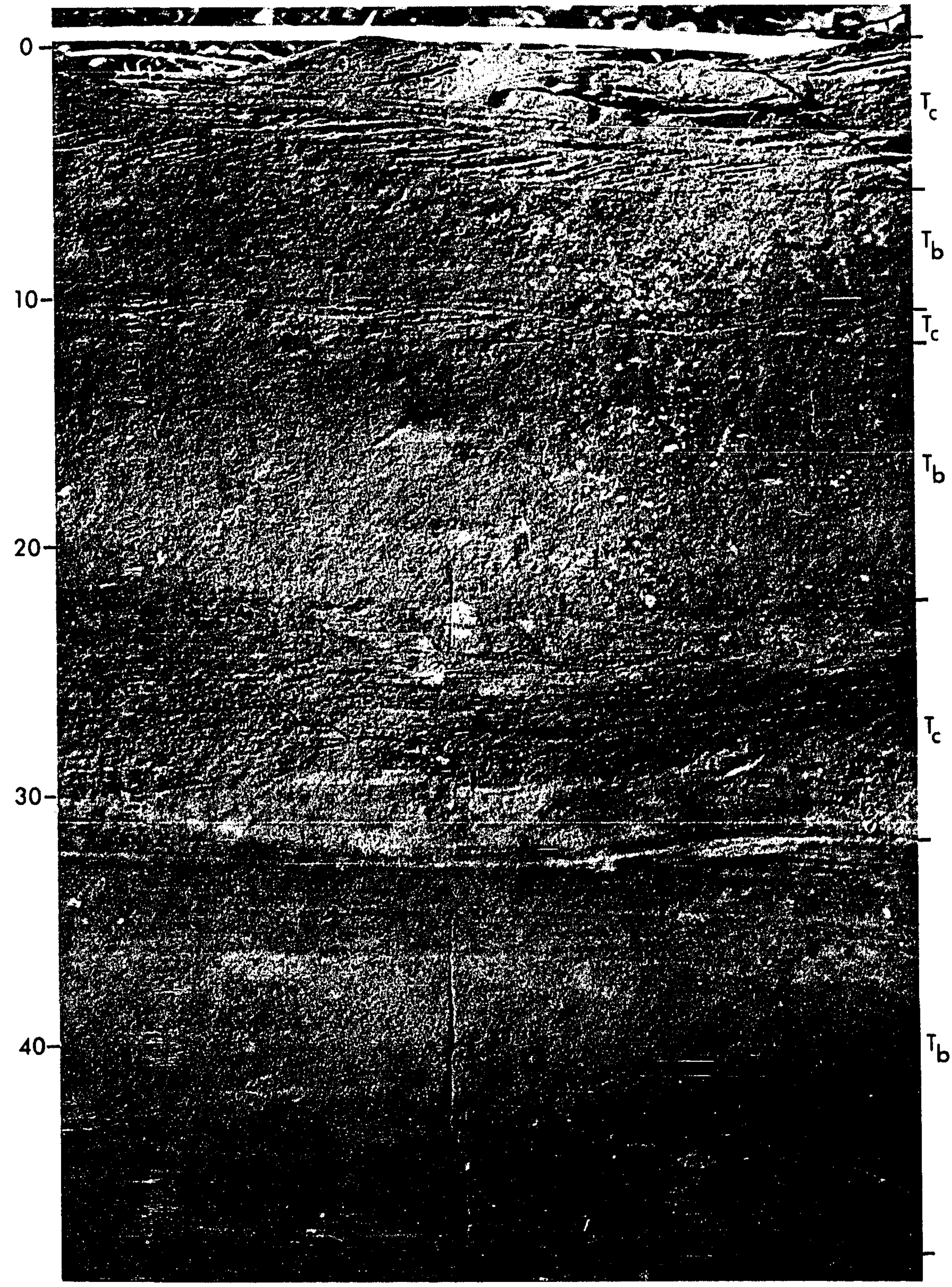
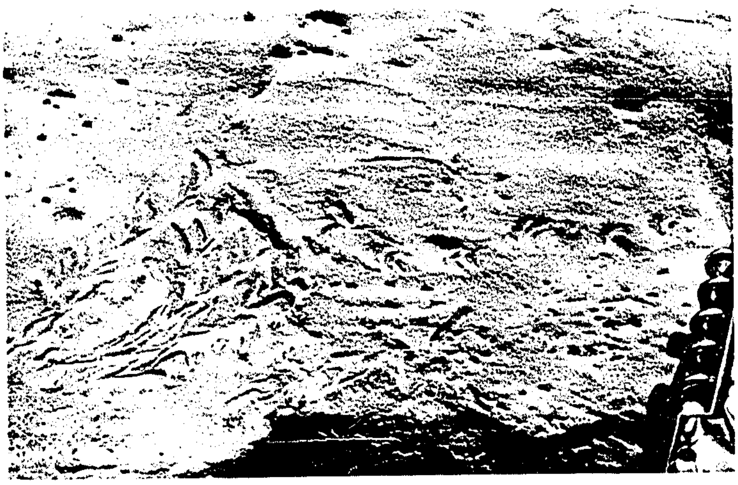
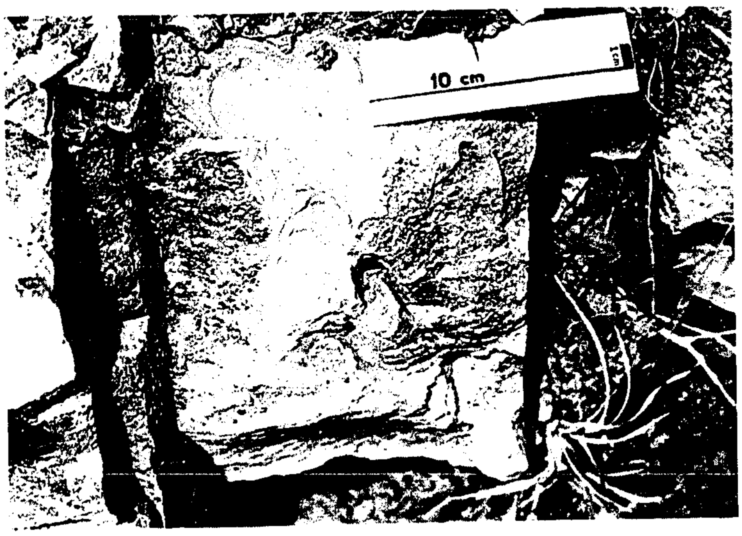

cm
0
10
20
30
40
T_c
T_b
T_c
T_b
T_c
T_b

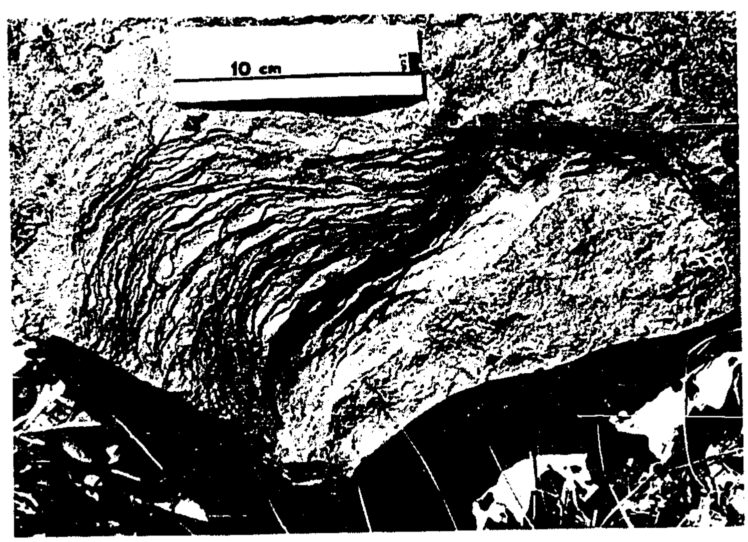
Plate 8



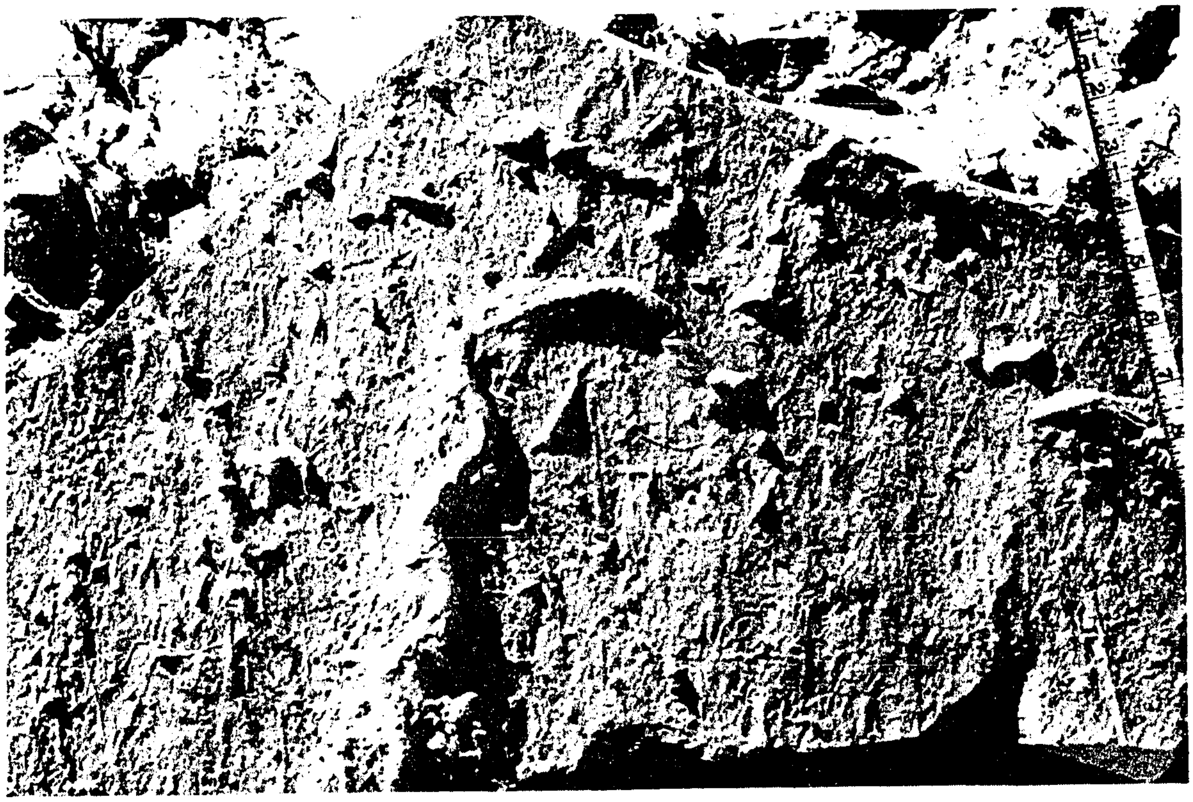
a.



b.



c.



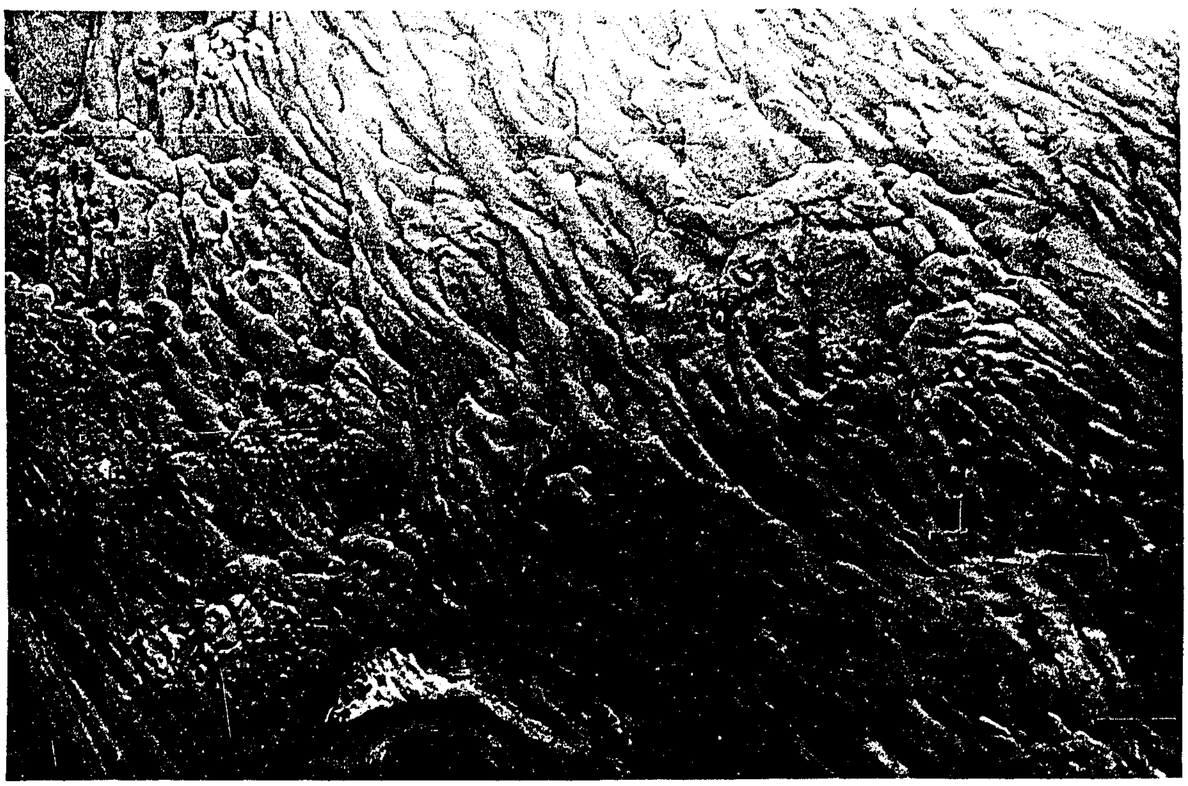
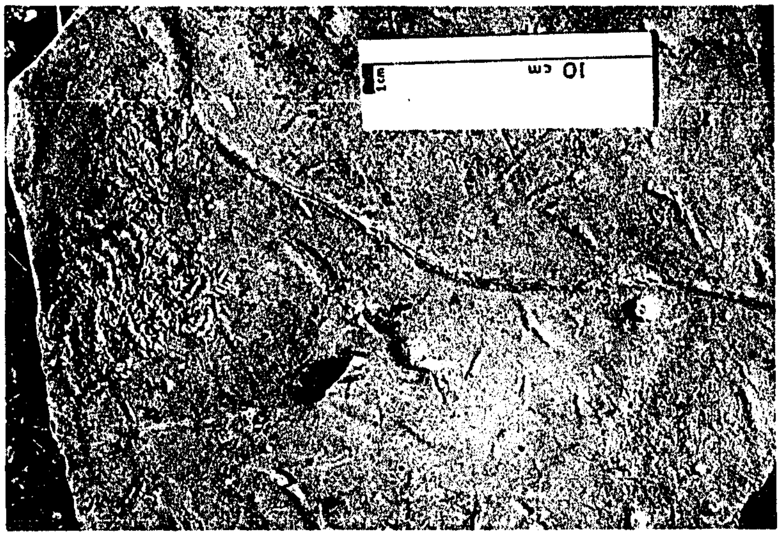


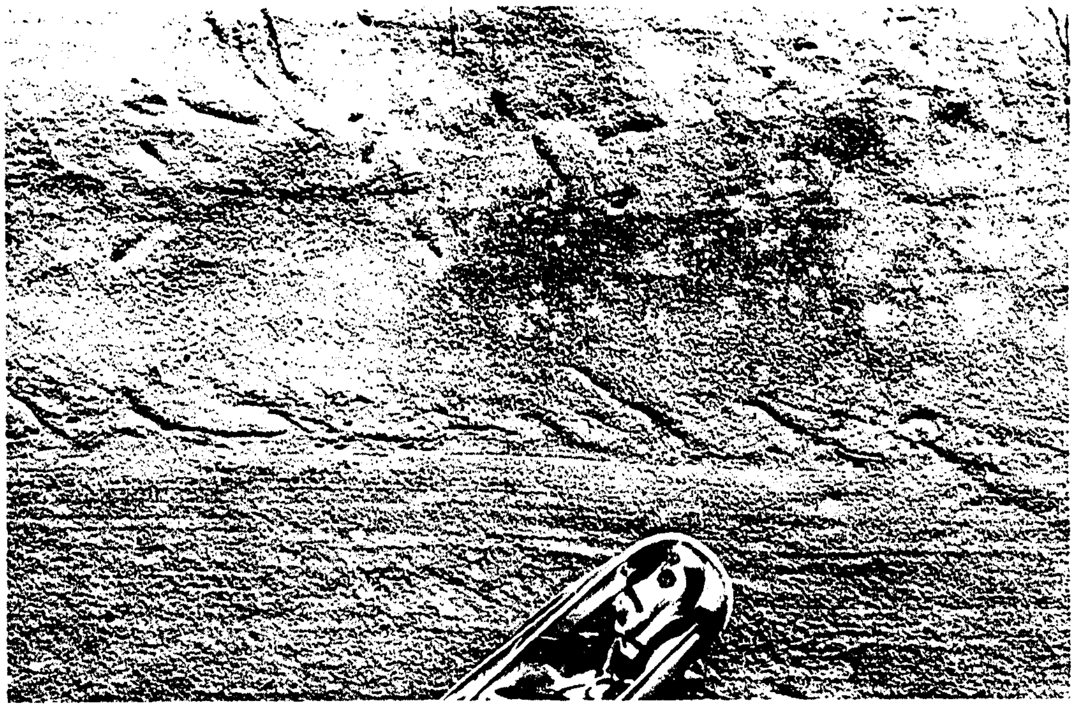
Plate 10

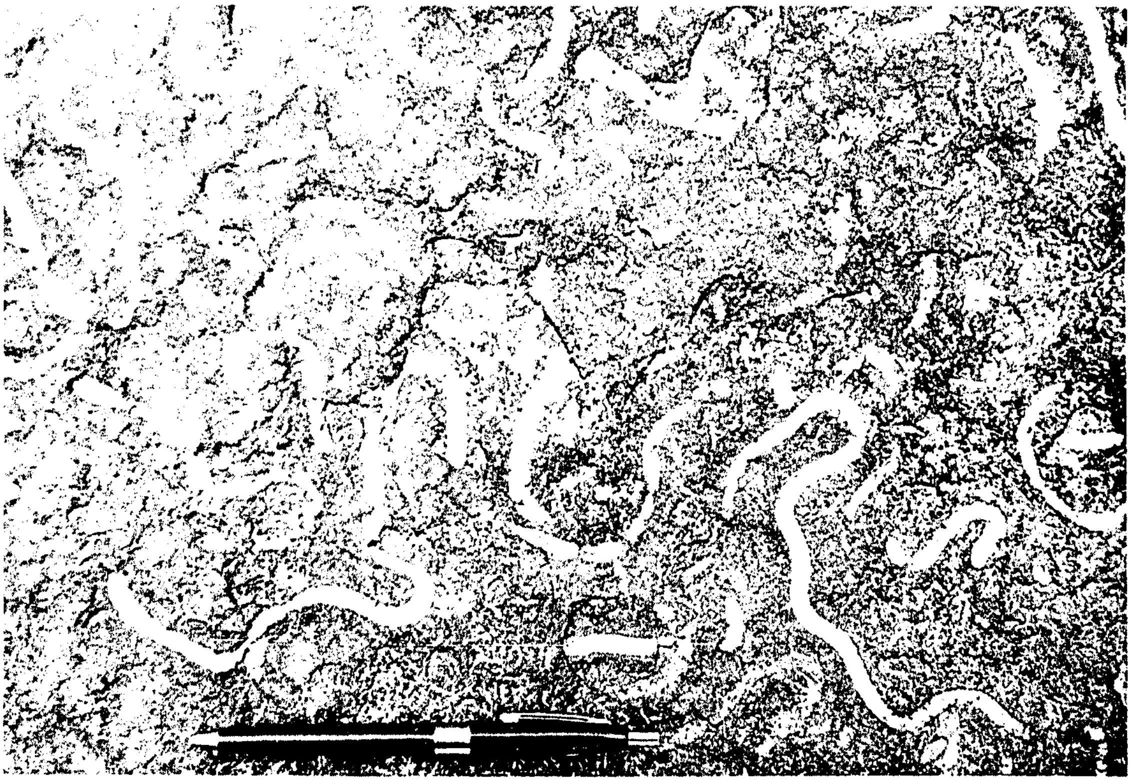


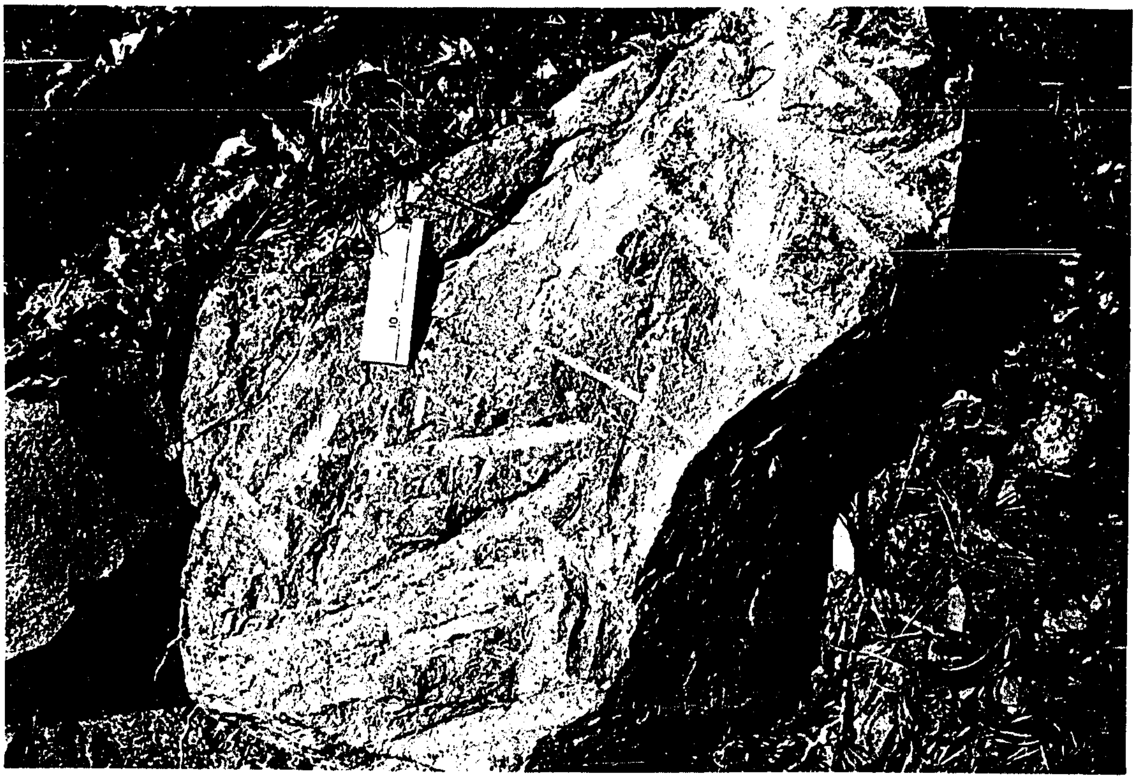
a.

b.

c.







UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Director*

Library of Congress catalog-card No. 73-176231

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 15 cents (paper cover)
Stock Number 2401-1223

Members of the Borden Formation (Mississippian) In North-Central Kentucky

By ROY C. KEPFERLE

CONTRIBUTIONS TO STRATIGRAPHY

GEOLOGICAL SURVEY BULLETIN 1354-B

Work done in cooperation with the Kentucky Geological Survey

A redefinition of the Holtsclaw Siltstone Member and a review of the stratigraphic relations brought out by geologic mapping

Kepferle--Appendix B (Pocket)

CONTENTS

ILLUSTRATIONS

CONTRIBUTIONS TO STRATIGRAPHY

MEMBERS OF THE BORDEN FORMATION (MISSISSIPPIAN) IN NORTH-CENTRAL KENTUCKY

By Roy C. Kepferle

ABSTRACT

The Borden Formation in north-central Kentucky consists of three widespread mappable units: a basal clay shale, a middle siltstone and silty shale, and an upper siliceous silty carbonate rock, respectively called the New Providence Shale Member, the Nancy Member, and the Muldraugh Member. These three mappable units have been recognized along the Mississippian escarpment west of the Cincinnati arch from Jefferson County, Ky., southward and eastward to Casey County, Ky. Two less widespread but locally mappable units are the Kenwood Siltstone Member and the Holtsclaw Siltstone Member of the Borden Formation. The Kenwood Siltstone lies on the New Providence Shale Member in easternmost outcrops in Jefferson and Bullitt Counties, Ky., and intertongues with the New Providence to the west and south. The Holtsclaw Siltstone Member is redefined from its original description in Jefferson County, Ky., where it lies on the Nancy Member and intertongues with the Nancy to the west and south. A widespread glauconitic zone, included in the base of the Muldraugh Member, is correlated with the glauconitic zone in the Floyds Knob Formation as used by Stockdale (1939).

INTRODUCTION

Current mapping in north-central Kentucky in cooperation with the Kentucky Geological Survey shows that previously named units of the Borden Formation are recognizable. In ascending order they are the New Providence Shale, Kenwood Siltstone, Nancy, Holtsclaw Siltstone, and Muldraugh Members. This report describes the use of units in the area from Jefferson County, Ky., southeastward to Casey County, Ky. (fig. 1), presents the historical development of stratigraphic names for the Borden Formation in Jefferson and Bullitt Counties, Ky. (fig. 2), and

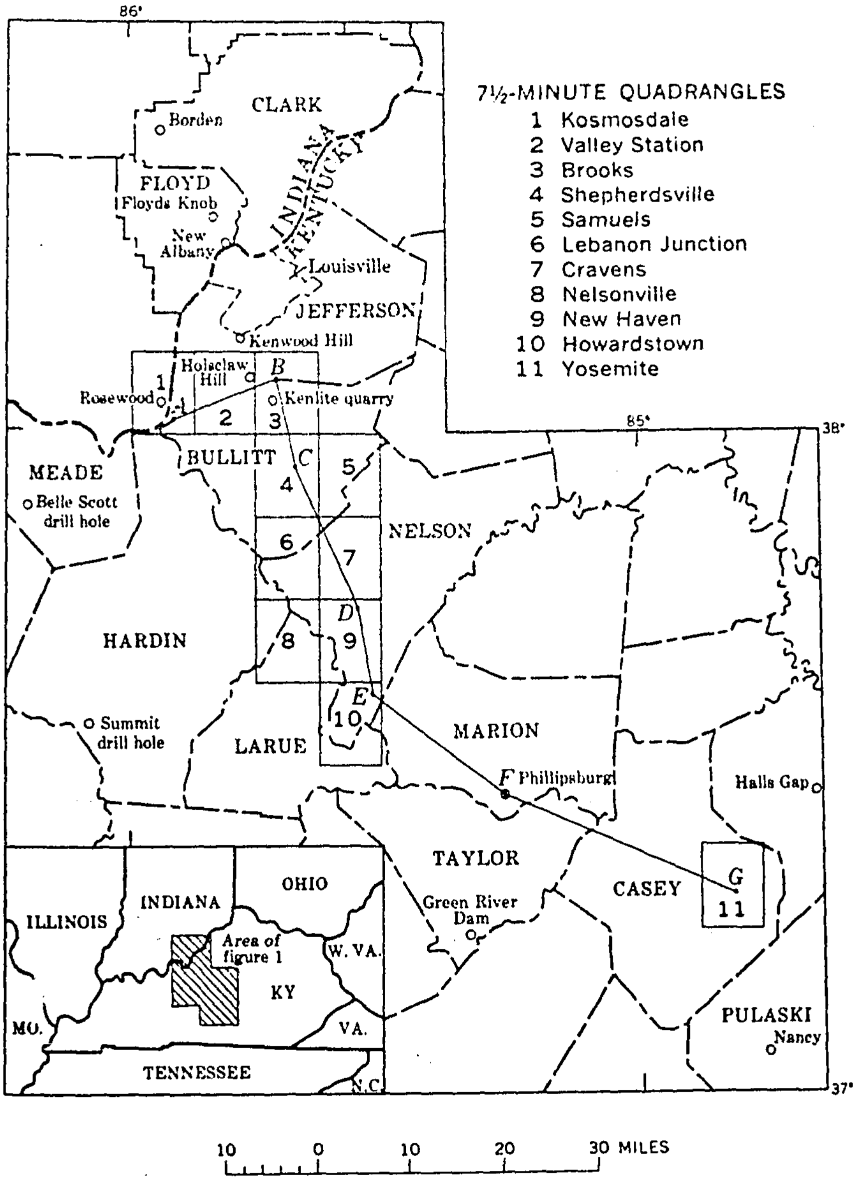
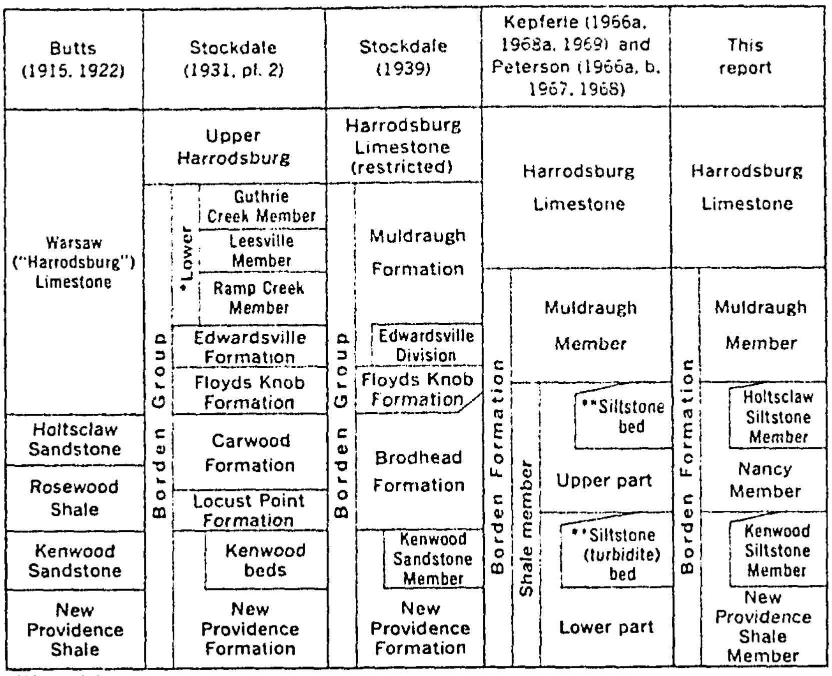


FIGURE 1.—Index map of north-central Kentucky and adjacent areas showing localities and lines of section referred to in text and in figures 3 and 4.



*Harrodsburg.
**Not on all reference maps.

FIGURE 2.—Development of stratigraphic nomenclature of the Borden Formation in north-central Kentucky.

illustrates stratigraphic relations brought out by mapping (figs. 3 and 4).

PREVIOUS NOMENCLATURE

BORDEN GROUP

The Borden Group was named by Cumings (1922) in Indiana, and was first applied by Stockdale (1931, pl. 2) in Kentucky to a sequence of clayey and silty shale and siltstone overlain by silty siliceous and clayey carbonate. The Borden Group was reduced to formational rank during the current mapping program in Kentucky. The following discussion includes only the major stratigraphic names used in north-central Kentucky. Previous nomenclature of Lower Mississippian rocks in north-central Kentucky is shown in figure 2.

New Providence Formation and Kenwood Sandstone

The New Providence Shale was named as a formation by Borden (1874) for exposures near New Providence (now Borden,

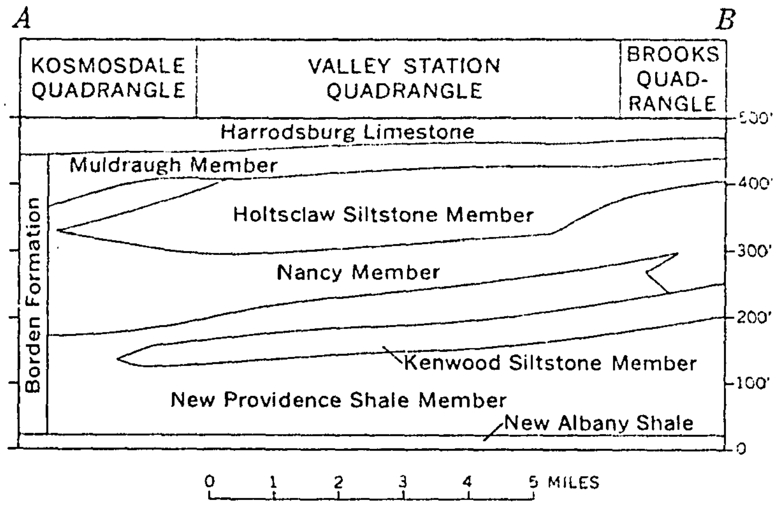


FIGURE 3.—Diagrammatic cross section along Jefferson County line showing units of the Borden Formation mapped in Kosmosdale, Valley Station, and Brooks quadrangles. Line of section shown in figure 1.

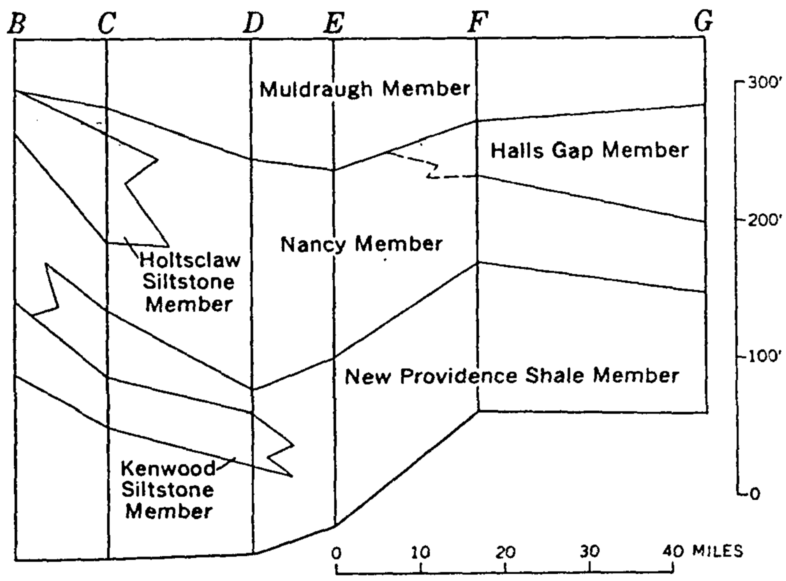


FIGURE 4.—Diagram showing relation of members of the Borden Formation from southernmost Jefferson County to Casey County. Line of section shown in figure 1.

fig. 1), Clark County, Ind. He described the formation as 80-120 feet of greenish shale that immediately overlies the Rockford Limestone (Lower Mississippian) which, in turn, overlies the New Albany Shale. Butts (1915, p. 135-147) used the name New Providence Shale for the green shale in Jefferson County that lies above the New Albany Shale and below a sequence of alternating siltstone and shale that he called the Kenwood Sandstone. The boundaries of the New Providence Shale as used by Butts (1915) differed from the boundaries at the type area in Indiana because the Kenwood is not present in the Indiana type area, and the Rockford Limestone is not present in Jefferson County. Not recognizing that the Kenwood drops stratigraphically relative to the base of the Borden together with the appearance and gradual increase in thickness of an overlying tongue of New Providence, Stockdale modified Butts' definition of the New Providence to include the Kenwood as the upper member of the New Providence Formation. Stockdale (1939, p. 108) believed the Kenwood cropped out only in Floyd County, Ind., and in Jefferson and Bullitt Counties, Ky. The Kenwood is now known to extend southward into the Nelsonville and New Haven quadrangles in Nelson County, Ky. (Peterson, 1966a, b). In these areas Stockdale included the Kenwood equivalents in the New Providence.

Rosewood, Holtsclaw, Locust Point, Carwood, and Brodhead Formations

The interval between the top of the Kenwood and the base of the carbonate sequence in north-central Kentucky was divided locally into two units: a basal silty shale and an overlying sandy siltstone called, respectively, the Rosewood Shale and Holtsclaw Sandstone by Butts (1915) and the Locust Point and Carwood Formations by Stockdale (1931).

Butts (1915, p. 150) assigned a total thickness of 190 feet to the bluish-gray unevenly fissile Rosewood Shale, named for exposures in Indiana, opposite Kosmosdale, Ky. The base was placed at the top of the Kenwood. The top of the shale was defined as the base of the Holtsclaw. Butts (1915, p. 152) assigned a thickness of 15-25 feet to the Holtsclaw Sandstone which, lying immediately below the base of his Warsaw ("Harrodsburg") Limestone, consisted of a "bluish-gray or buffish, rather loosely cemented, soft and easily disintegrated, very fine-grained, thick to massive bedded stratum * * *." He described the basal part as being commonly gradational with the underlying Rosewood.

In a section measured at Holsclaw Hill in Jefferson County, Stockdale (1931, p. 113) assigned the upper 68 feet of the interval between the top of the Kenwood and the base of the overlying carbonate sequence to the Carwood Formation and the lower 163 feet of the interval to the Carwood(?) and Locust Point Formations, the upper 28 feet of which graded into the overlying massive rock. Stockdale later (1939, p. 140) assigned the entire 231-foot interval to the Brodhead Formation. Weir, Gualtieri, and Schlanger (1966, p. F6) recently abandoned the name Brodhead because the unit was not defined in terms of its lithology and was therefore not mappable as originally defined.

Floyds Knob Formation

Stockdale (1931, p. 193-196) named a thin unit of glauconitic silt and limestone the Floyds Knob Formation, designating the type locality near Floyds Knob, Ind., and later traced this marker bed around the exposures of Lower Mississippian rocks from Indiana through Kentucky, nearly to Ohio (1939, p. 84). He stated (1939, p. 84) "It is an all-important 'key' horizon in the tracing of the lithologic facies of strata both above and below and in establishing correlations across the region." In north-central Kentucky the unit is commonly represented by a single layer of glauconitic silt. Locally, however, it is composed of two thin layers separated by as much as 15 feet of silty dolomite, greenish siltstone, or brownish-gray oolitic limestone. Stockdale misidentified the unit in southeastern Hardin and eastern Larue Counties, Ky., because he did not recognize the abrupt drop of the glauconitic bed(s) relative to the base of the Borden. The recent mapping of this drop (Peterson, 1966a, b; Kepferle, 1966a) emphasizes the pertinence of the Floyds Knob as a key horizon. However, because the Floyds Knob is generally too thin to be considered a mappable unit, it has been included on some recent maps with the overlying Muldraugh Member (Peterson, 1967, 1968; Kepferle, 1968a) and on others with the underlying shale member (Kepferle, 1966a, b, 1967; Peterson, 1966a, b; Weir, 1970, p. 33), according to the affinities of the lithologies represented.

Muldraugh Formation

The Muldraugh Formation was named by Stockdale (1939, p. 200) for exposures of "calcareous, cherty rock" south of Phillipsburg, Marion County, Ky. He equated the unit with the combined Edwardsville and Lower Harrodsburg division in Indiana. The lower contact was the top of the glauconitic Floyds Knob Formation; the upper contact in the area from Jefferson to

Marion Counties was defined as the base of crinoidal limestone of the Harrodsburg Limestone (restricted). Weir, Gualtieri, and Schlanger (1966, p. F22) redefined the base to include cherty and dolomitic limestone and siltstone "a few feet to several tens of feet below the glauconitic siltstone that Stockdale (1939) assigned to the Floyds Knob Formation." More recently Weir (1970, p. 33) conformed to Stockdale by placing the base of the Muldraugh at the top of the uppermost glauconite seam.

Sable, Kepferle, and Peterson (1966) revised the upper contact to exclude all the typical Harrodsburg Limestone as manifested in the equivalents of the Guthrie Creek Member and Leesville Limestone Member of Stockdale (1929, p. 239-240). In part of south-central Kentucky, rocks correlative with the Harrodsburg Limestone are included in the Salem and Warsaw Limestones (Weir and others, 1966, p. F8). To the east, as lithology recognizable as typical Harrodsburg becomes more obscure, the top of the Muldraugh is placed at the base of a persistent sand bed forming the base of the Salem Formation (Weir, 1970, p. 34).

PRESENT NOMENCLATURE

BORDEN FORMATION

The Borden Formation in north-central Kentucky consists of three widespread mappable units: a basal clay shale, a middle siltstone and silty shale, and an upper siliceous silty carbonate rock called, respectively, the New Providence Shale Member, the Nancy Member, and the Muldraugh Member. Two less widespread but locally mappable units are the Kenwood Siltstone and the Holtsclaw Siltstone Members of the Borden Formation. The thickness of the formation here ranges from about 220 feet in the south to 425 feet in the northern part of the study area. Phosphate nodules in a greenish-gray clay shale matrix mark the basal foot of the Borden, which lies conformably on the black fissile-weathering New Albany Shale. The Borden is overlain with apparent conformity by the pelmatozoan-bryozoan limestone of the Harrodsburg Limestone.

New Providence Shale Member

The unit here designated as the New Providence Shale Member of the Borden Formation is generally the same as the unit termed the lower part of the shale member of the Borden Formation (fig. 2) on geologic quadrangle maps of areas in Bullitt, Hardin, Nelson, Larue, and Marion Counties (Kepferle, 1966a, 1967, 1968a, 1969; Peterson, 1966a, b, 1967, 1968). In detail, an exception is the inclusion of beds that now would be assigned to the Kenwood Siltstone Member. The unit has been mapped as the New Providence Shale Member in the Yosemite quadrangle in Casey County (Taylor and Lewis, 1971) and in Brooks, Valley Station, and Kosmosdale quadrangles, Jefferson and Bullitt Counties (Kepferle, 1971a, b).

As its name implies, the New Providence Shale Member is chiefly shale. It is dark greenish gray, medium gray, or less commonly reddish gray and weathers light greenish gray to yellowish gray. Size analyses indicate that it is composed of nearly equal amounts of clay and silt-sized particles and has a trace of very fine sand (Peterson, 1966b). The silt is quartzose, and the silt content increases upward in the member. Siderite concretions as much as 2 feet in diameter occur sparsely to abundantly along the bedding planes. Flattish phosphate nodules as much as a foot long are very abundant in the basal 12 inches, and scattered smaller nodules occur higher in the unit. The basal nodule-bearing zone, included in the New Albany Shale by Lineback (1968, p. 1300-1301), is correlated with the nodule-bearing zone that underlies the Rockford Limestone in Indiana. The shale is noncalcareous except for local small limestone concretions, scattered crinoidal debris, and rare thin lenses of crinoidal limestone. Dolomite, pyrite, and cone-in-cone concretionary carbonate layers are rare.

The thickness of the New Providence Shale Member is commonly less than 120 feet, although in outcrop its range is from about 250 feet in the Brooks and Valley Station quadrangles (fig. 1) to 55 feet in the Howardstown and Nelsonville quadrangles. The unit thins irregularly to the south and west. It is 50 feet thick in the core of a hole drilled at the Belle Scott quarry in Meade County, Ky. (Kepferle and Peterson, 1964), less than 5 feet thick in the core at Summit, Ky. (Moore, 1964), and 15 feet thick in the core at Green River Dam, Taylor County, Ky. (See fig. 1.) Most of this thinning occurs west of a line extending roughly through the southeast corner of the Howardstown quadrangle and the southwest corner of the Kosmosdale quadrangle and is ascribed to nondeposition rather than to erosion (Peterson and Kepferle, 1970).

West of this line the New Providence is overlain mainly by the Muldraugh Member and is separated from the Muldraugh by a disconformable contact commonly marked by a glauconite-rich zone. Eastward the New Providence Member is overlain mainly by the silty shale of the Nancy Member, except for an area in central Jefferson and northern Bullitt Counties, where it is overlain by the Kenwood Siltstone Member. (See fig. 3.) The upper part grades into the Nancy Member, the contact marked only by a subtle upward increase in silt content in the section. The higher silt content imparts greater resistance to the shale and produces steeper and more stable slopes in the Nancy Member, in contrast to gentler slopes that result from slump, sliding, and creep in the less resistant clay shale of the New Providence Shale Member.

The New Providence is readily distinguished from the dark brittle New Albany Shale on which it lies with an abrupt conformable contact.

Kenwood Siltstone Member

The Kenwood Sandstone, named by Butts in 1915 (p. 148-150), is here redesignated the Kenwood Siltstone Member of the Borden Formation. The type exposure is on Kenwood Hill in the southeast part of the Louisville West 7½-minute quadrangle, Jefferson County, Ky. The Kenwood Siltstone Member has been mapped or recognized from the New Haven quadrangle in Kentucky northward into Floyd County, Ind. Its stratigraphic relations are diagrammed in figures 3 and 4. A reference section at Kenlite quarry in Bullitt County, Ky., is described on page B14. The Kenwood Siltstone Member is a sequence of alternating siltstone and shale. The siltstone is light gray to medium gray, weathers yellowish gray, and is generally limonite stained on bedding surfaces and joints. The staining is from oxidation of pyrite which is locally common. Graded, laminated, and ripple bedding and sole marks indicate that the silt was deposited from turbidity currents (Kepferle, 1968b). Individual beds are from less than 0.1 foot to more than 20 feet thick, but commonly are less than 1 foot thick. They occur singly or in a sequence of as many as 30 tabular beds, reaching a maximum aggregate thickness of 100 feet in the Samuels quadrangle (Kepferle, 1969). The shale at places makes up more than 60 percent of the unit.

On Kenwood Hill, in South Park Hills in the Brooks quadrangle, and in the Samuels and New Haven quadrangles, the Kenwood lies above the New Providence Shale Member and below the Nancy Member. South and west it drops stratigraphically from 5 to 20 feet per mile relative to the base of the Borden Formation by intertonguing with the New Providence Shale Member. The Kenwood pinches out within a few feet of the base of the New Providence in the Lebanon Junction quadrangle (Peterson, 1967).

Nancy Member

The Nancy Member was named for exposures of the basal Borden Formation in Pulaski County, Ky., by Weir, Gualtieri, and Schlanger (1966, p. F11-F13). A basal light-greenish-gray clay shale described by Weir (1970, p. 44) in the lower part of the Nancy at Halls Gap is probably equivalent to the New Providence Shale Member of this report. The usage of the name Nancy Member is herein extended northwestward and is applied to the unit mapped by Peterson (1966a, b, 1967, 1968) and Kepferle (1966a, b, 1967, 1968a, 1969) as the upper part of the shale member of the Borden Formation in north-central Kentucky west of the Cincinnati arch. The Nancy Member in this area, chiefly greenish gray to olive gray and comprising clayey to argillaceous silty shale and shaly siltstone, minor resistant siltstone, and thin discontinuous lenses of crinoidal limestone and clayey shale, lies below the Muldraugh or Holtsclaw Siltstone Members and above the New Providence Shale or the Kenwood Siltstone Members (figs. 2-4). A description of the Nancy Member is included as part of the reference section of the Holtsclaw Siltstone Member (p. B12).

The abrupt disconformable contact between the Nancy Member and the overlying Muldraugh Member is commonly marked by a thin glauconitic siltstone locally associated with an oolitic limestone as much as 12 feet thick in the Muldraugh. Locally in Jefferson and Bullitt Counties, the Nancy Member intergrades with the overlying Holtsclaw Siltstone Member, and the contact between the two is placed at the lowest continuous ledge-forming siltstone bed within the zone of gradation.

Holtsclaw Siltstone Member

The Holtsclaw Sandstone of Butts (1915, p. 148-150) is herein redefined as the Holtsclaw Siltstone Member of the Borden Formation. Detailed mapping indicates that this unit thickens to as much as 130 feet to the south and west before grading into the Nancy Member.

The Holtsclaw Siltstone Member is equivalent to the unnamed siltstone in the upper part of the shale member of the Borden Formation in the Shepherdsville quadrangle (Kepferle, 1968a) and to Stockdale's (1939, p. 147) Lebanon Junction Siltstone Member of the Brodhead Formation. It is similar to the Halls Gap Member of the Borden Formation in south-central Kentucky (Weir and others, 1966). The Holtsclaw pinches out within a few miles south and west of the type section.

No type section was designated by Butts (1915, p. 151-152), who named the unit for exposures on Holtsclaw Hill, now called Holsclaw Hill on the recommendation of the U.S. Board on Geographic Names. However, because of long established usage, the original spelling of the geologic unit is retained. A type section is here designated along Holsclaw Hill Road on the west side of the ravine west of Holsclaw Hill, Valley Station quadrangle, Jefferson County, and is presented on pages B12 B13. The top of the section is 2.3 miles south of Fairdale, one-fifth of a mile west of the Holsclaw Lookout tower in Jefferson County Memorial Forest; the base of the section is in the creek bed west of the road, about 1.8 miles south of Fairdale. The unit is chiefly medium-gray to olive-gray siltstone that weathers yellowish gray or light olive gray. The silt, somewhat calcareous and clayey, is medium to fine according to size analyses and locally is interbedded with thin shale and crinoidal limestone. The Holtsclaw Siltstone is distinguishable from the Nancy Member on the basis of topographic expression. The Holtsclaw tends to weather to massive cliffs or steep smooth surfaces on southwest-facing slopes in contrast to the shaly slopes characteristic of the Nancy. The Holtsclaw is less clayey than the Nancy.

The siltstone of the Holtsclaw intergrades and intertongues with the shale of the Nancy. Where the Holtsclaw is overlain by the Muldraugh Member, the upper boundary is abrupt and is marked by the distinct basal glauconitic marker bed of the Floyds Knob Formation as used by Stockdale (1939). (See figs. 2-4.)

Muldraugh Member

The Muldraugh Member as here used is the same as that modified from Stockdale (1939) by Weir, Gualtieri, and Schlanger (1966, p. F36-F37) from the type section south of Phillipsburg, Marion County. Throughout, the member consists of a complexly interstratified sequence of yellowish-gray- to light-olive-gray-weathering dolomitic siltstone, silty dolomite, and coarse crinoidal limestone with common to abundant geodes and chert. Nearly everywhere, the base of this unit is marked by glauconite, commonly in a single layer, but locally in two thin layers separated by a sequence which includes as much as 15 feet of silty dolomite, greenish siltstone, or brownish-gray oolitic limestone somewhat dissimilar from the units above and below. This glauconite and associated sequence includes beds that Stockdale (1931, p. 193-217) named the Floyds Knob Formation. Although this unit is persistent throughout most of the area of outcrop of Lower Mississippian rocks in north-central Kentucky, it nowhere attains a mappable thickness. Nevertheless, it is valuable as a marker bed at the base of the Muldraugh Member. In and southeast of southern Nelson County, the glauconitic bed(s) have been included with equivalents of the Nancy Member as defined by Weir (1970, p. 33).

The upper contact of the Muldraugh Member in north-central Kentucky is placed at the base of the Harrodsburg Limestone as modified from Stockdale (1939) by Sable, Kepferle, and Peterson (1966). The lower contact of the Muldraugh Member is described in the discussion of the underlying units.

MEASURED SECTIONS

Holsclaw Hill section

[Type section of the Holtsclaw Siltstone Member of the Borden Formation. Measured with barometer, hand level, and tape by E. G. Sable and R. C. Kepferle, October 1962; revised by Kepferle, August 1970; along Holsclaw Hill Road on west side of ravine west of Holsclaw Hill, Jefferson County. The top of the section is the top of the hill 2.3 miles south of Fairdale, Ky. (Valley Station quadrangle)]

	Thickness (feet)
Mississippian:	
Harrodsburg Limestone (incomplete):	
24. Limestone, cherty, deeply weathered	23
Borden Formation (incomplete):	
Muldraugh Member:	
23. Limestone, dolomitic, cherty; weathers pale yellowish orange (10*YR* 8/6);[1] poorly exposed	17
22. Limestone, crinoidal; partly silicified to chert in beds 0.3 ft thick; interbedded with limestone as below	5
21. Limestone, dolomitic, very fine grained, medium-light-gray (*N*6) to light-gray (*N*7); weathers pale yellowish orange (10*YR* 8/6) to dark yellowish orange (10*YR* 6/6); obscurely laminated and has "knotty" appearance around small quartz geodes 1-2 cm (centimeters) in diameter; poorly exposed; some beds as much as 1 ft thick; splits with irregular parting to beds commonly 0.1-0.3 ft thick	30
20. Siltstone, dolomitic; weathers dark yellowish orange (10*YR* 6/6); small quartz geodes 1-2 cm in diameter	.9
19. Mudstone, clayey, glauconitic; weathers pale brown (5*YR* 5/2); dusky-green (5*G* 3/2) to greenish-black (5*GY* 2/1) glauconitic pellets concentrated along bedding planes	.7
18. Limestone, light-brownish-gray (5*YR* 6/1); fine to medium fossil fragments with scattered coarse fossil debris including crinoids; oolitic; very finely cross laminated; in a single bed having basal relief of as much as 0.4 ft in sharp contact with underlying unit. This	

[1] Color names with numbers based on "Rock-Color Chart," by Goddard and others (1948).

Holsclaw Hill section—Continued

	Thickness (feet)
Mississippian—Continued	
Borden Formation—Continued	
Muldraugh Member—Continued	
and unit 19 are equivalent to the Floyds Knob Formation as defined by Stockdale (1931)	1.8
Total Muldraugh Member	55.4
Holtsclaw Siltstone Member:	
17. Siltstone, yellowish-gray (5*Y* 7/2); in thin planar beds 0.1 ft thick; contains brachiopods and bryozoan fragments; upper part contains thin silty clay shale interbeds	1.5
16. Siltstone, greenish-gray (5*GY* 6/1); weathers yellowish gray (5*Y* 7/2); slightly sandy, massive, with incipient partings 1-3 ft apart; scattered orthotetid brachiopods	5.9
15. Siltstone, light-greenish-gray (5*G* 8/1); calcareous; partings irregular, average 0.1 ft; grades laterally to more massive limy siltstone; bryozoan bearing	.7
14. Siltstone, greenish-gray (5*GY* 6/1) to dark-greenish-gray (5*GY* 4/1); weathers dark yellowish orange (10*YR* 6/6) to moderate yellowish brown (10 *YR* 5/4); slightly sandy, dominantly massive; discontinuous laminations transected by darker clay lenses 1 mm (millimeter) thick and 1 cm across that may represent burrow cross sections	24.7
13. Limestone, medium-gray (*N*5) to brownish-gray (5*Y* 4/1); crinoidal fossil fragments; silty admixture; matrix microgranular; clay partings 0.1-0.3 ft apart	1.3
12. Siltstone, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2) to pale olive (10*Y* 6/2) or pale yellowish brown (10*YR* 6/2); shaly in part; poorly to moderately resistant to weathering; partings as much as 0.5 ft thick average 0.1 ft thick; very porous; contains more clay in lower 16 feet than in upper 10 feet	26.5
11. Siltstone, olive-gray (5*Y* 4/1); having commonly limonite-stained calcareous scattered crinoid columnals	.5
10. Covered	5.3
9. Siltstone, moderate-yellowish-brown (10*YR* 5/4) to dark-yellowish-orange (10*YR* 6/6), sandy, weathered; juts out above unit below; small pits on surface due to differential weathering of borings	1.0
8. Siltstone, yellowish-gray (5*Y* 7/2) to medium-light-gray (*N*6), slightly iron stained; irregularly shaly bedded; grades laterally to massive weathering face; indistinct irregular laminae; scattered medium-dark-gray (*N*4) ellipsoidal to spherical 0.1-0.5-ft-thick limestone concretions that weather with dark iron stain; vertical *Zoophycos* markings as much as 0.2 ft long	32.8
Total Holtsclaw Siltstone Member	100.2

Holsclaw Hill section—Continued

	Thickness (feet)
Mississippian—Continued	
Borden Formation—Continued	
Nancy Member:	
7. Shale, light-olive-gray (5Y 5/2); weathers same; silty, clayey; clay-filled borings; hackly parting; sideritic concretions as much as 0.2 ft thick; poorly exposed	14.0
6. Covered	23.9
5. Shale, light-olive-gray (5Y 5/2); weathers same; silty, clayey; grades laterally into clayey shale	15.9
Total Nancy Member	53.8
Upper tongue of New Providence Shale Member:	
4. Covered, probably like unit 3 below	70
3. Clay shale, light-olive-gray (5Y 5/2) to greenish-gray (5Y 6/1); weathers greenish gray	5.0
Total upper tongue of New Providence Shale Member	75
Kenwood Siltstone Member (elev 585 ft by altimeter):	
2. Siltstone, yellowish-gray (5Y 7/2), resistant; in single bed; limonite stained at base	.5
1. Shale, olive-gray (5Y 6/2) to greenish-gray (5GY 6/1); clayey; base not observed	5+
Total Kenwood Siltstone Member	5.5+
Total Borden Formation	290+

Kenlite quarry section

[Reference section of the Kenwood Siltstone and the lower tongue of the New Providence Shale Members of the Borden Formation. Measured with altimeter, hand level, and tape by E. G. Sable and R. C. Kepferle, October 1962; up west face of Kenlite quarry, half a mile west of State Highway 1020 and 1.6 miles south of Brooks, Bullitt County (Brooks quadrangle)]

	Thickness (feet)
Mississippian:	
Borden Formation (incomplete):	
Upper tongue of New Providence Shale Member(?):	
37. Covered to top of ridge, probably clay shale	2.5
Kenwood Siltstone Member:	
36. Siltstone, well-jointed bed	.4
35. Clay shale, medium-gray (N5); weathers light olive gray (5Y 5/2); interbedded with clayey silt shale	6.0
34. Siltstone, sandy; thin lens	.1
33. Clay shale, poorly exposed	1.4
32. Siderite concretions, iron-oxide-coated	.2
31. Clay shale, very silty, poorly exposed	3.0
30. Siltstone; limonite cemented in part	.5

Mississippian—Continued
Borden Formation—Continued
Kenwood Siltstone Member—Continued

	Thickness (feet)
29. Clay shale, silty, weathered	1.1
28. Siltstone	.8
27. Clay shale, silty; contains nodular siderite concretions	4.9
26. Siltstone and clay shale, interbedded; thins along line of section from a maximum of 5.0 ft to 0.9 ft siltstone, 0.4 ft shale, 0.6 ft siltstone, 0.7 ft shale, and 0.3 ft siltstone; sole marks on siltstone beds	2.9
25. Clay shale, similar to unit 23; iron stained in part	1.7
24. Siltstone, similar to unit 22; sandy; single massive bed with local limonite concentrations	1.8
23. Clay shale, medium-gray (*N*5), silty; weathers light olive gray (5*Y* 5/2)	2.0
22. Siltstone, yellowish-gray (5*Y* 7/2), sandy; limonite along partings in lower 0.5 ft; upper part massive	1.9
21. Clay shale, dark-gray (*N*3); weathers medium light gray (*N*6) with blue tint	.8
20. Siltstone, yellowish-gray (5*Y* 7/2), sandy, micaceous	.5
19. Clay shale, grayish-olive (10*Y* 4/2), silty; in slightly weathered lower half, fresh surface is dark gray (*N*3)	2.3
18. Siltstone, moderate-yellowish-brown (10*YR* 5/4); weathers dark yellowish orange (10*YR* 6/6) to dark reddish brown (10*R* 3/4); sandy	3.6
17. Clay shale, dark-gray (*N*3) to medium-dark-gray (*N*4); weathers with a blue tint or to yellowish gray (5*Y* 7/2); silty, micaceous; weathers shaly to nodular; reddish-brown 2-mm-wide markings resembling reed impressions or straight borings on bedding surface; medium-light-gray (*N*6) siderite concretions which weather yellowish brown and are 0.4 ft thick and 0.8 ft in diameter	4.2
16. Siltstone, similar to unit 18; sandy	2.0
Total Kenwood Siltstone Member	42.1

Lower tongue of New Providence Shale Member:

15. Clay shale, medium-gray to medium-dark-gray (*N*3-4); weathers medium light gray (*N*5); slightly micaceous; siltier than underlying unit; shaly parting enhanced by weathering; gypsum in veinlets along partings. Contains layers of brownish-gray (5*YR* 4/1) to light-brown (5*YR* 5/6) spheroidal siderite concretions that weather moderate red (5*R* 4/6) to dark yellowish orange (10*YR* 6/6); septarian; fractures filled with calcite and celestite; contain crinoid plates	13.3
14. Clay shale, similar to unit 15 but somewhat less silty; ellipsoidal siderite concretions fairly abundant, as much as 0.5 by 1.5 ft	15.9
13. Covered	3.0
12. Clay shale, dark-greenish-gray (5*G* 4/1); weathers	

Kenlite quarry section—Continued

	Thickness (feet)
Mississippian—Continued	
Borden Formation—Continued	
Lower tongue of New Providence Shale Member—Continued	
medium gray (*N*4) to medium light gray (*N*5); uppermost 0.2 ft fossiliferous with crinoid columnals and well-preserved brachiopods; scattered ellipsoidal to rounded siderite concretions 0.3 by 0.5 ft	28.8
11. Siderite concretions, discontinuous lenses	.2
10. Clay shale, greenish-black (5*G* 2/1); parting irregular, blocky; scattered concretionary lenses in lower 5 ft	14.6
9. Clay shale, greenish-gray (5*G* 6/1) to dark-greenish-gray (5*G* 4/1); in cross section grayish-red (10*R* 4/2) lenticular borings 1 mm wide on bedding planes; small phosphatic nodules as much as 0.1 ft in diameter	13.5
8. Clay shale, olive-gray (5*Y* 4/1); weathers greenish gray (5*G* 6/1); unctuous; markings on bedding plane like those in unit 17	12.0
7. Clay shale, dark-greenish-gray (5*GY* 4/1); similar to unit 5 below	5.5
6. Siderite concretions, lenses as much as 0.3 ft thick; interbedded with shale; 1-2.5 ft lateral extent	1.0
5. Clay shale, weathers medium light gray (5*GY* 4/1); poorly exposed	7.5
4. Clay shale, olive-gray (10*Y* 4/2) to dark-greenish-gray (5*G* 6/1); slightly silty; blocky with irregular smooth horizontal parting 0.02 ft apart; large sideritic concretions in float	3.0
3. Clay shale, greenish-gray (5*GY* 6/1) to dark-greenish-gray (5*G* 4/1); lower 0.1 ft contains dark-yellowish-orange (10*YR* 6/6) and dark-yellowish-brown (10*YR* 4/2) silty concretionary phosphate nodules; upper 0.1 ft contains medium-gray (*N*5) to medium-dark-gray (*N*4) phosphatic(?) concretions with granular centers	.8
2. Clay and clay shale; dark-yellowish-orange (10*YR* 6/6) clay; greenish-gray (5*GY* 6/1) clay shale	.2
Total lower tongue of New Providence Shale Member	119.3
Total Borden Formation	163.9
Devonian:	
New Albany Shale (elev 551 ft by altimeter):	
1. Shale, grayish-black (*N*2) to brownish-black (5*YR* 6/1); phosphate and pyrite nodules commonly 0.1 ft in diameter. U.S. Geol. Survey fossil locality 7656-SD at base of exposure in which are conodonts of Late Devonian age	3.5+

REFERENCES CITED

Borden, W. W., 1874, Report of a geological survey of Clarke and Floyd Counties, Indiana: Indiana Geol. Survey 5th Ann. Rept., p. 134-189.

Butts, Charles, 1915, Geology and mineral resources of Jefferson County, Kentucky: Kentucky Geol. Survey, ser. 4, v. 3, pt. 2, 270 p.

——— 1922, The Mississippian series of eastern Kentucky: Kentucky Geol. Survey, ser. 6, v. 7, 188 p.

Cumings, E. R., 1922, Nomenclature and description of the geological formations of Indiana, *in* Handbook of Indiana geology: Indianapolis, Indiana Dept. Conserv. Pub. 21, pt. 4, p. 403-570.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, D.C., Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Kepferle, R. C., 1966a, Geologic map of the Howardstown quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-505.

——— 1966b, Geologic map of the Elizabethtown quadrangle, Hardin and Larue Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-559.

——— 1967, Geologic map of the Colesburg quadrangle, Hardin and Bullitt Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-602.

——— 1968a, Geologic map of the Shepherdsville quadrangle, Bullitt County, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-740.

——— 1968b, Turbidites in the Lower Mississippian Borden Formation of central Kentucky [abs.]: Geol. Soc. America Spec. Paper 115, p. 390-391.

——— 1969, Geologic map of the Samuels quadrangle, north-central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-824.

——— 1971a, Geologic map of the Brooks quadrangle, Bullitt and Jefferson Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-961. (In press.)

——— 1971b, Geologic map of the Valley Station quadrangle and part of the Kosmosdale quadrangle, north-central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-962. (In press.)

Kepferle, R. C., and Peterson, W. L., 1964, Lithologic and radioactivity log of Bell Scott quarry drill hole, Meade County, Kentucky: U.S. Geol. Survey open-file report, 1 sheet.

Lineback, J. A., 1968, Subdivisions and depositional environments of New Albany Shale (Devonian-Mississippian) in Indiana: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 1291-1303.

Moore, F. B., 1964, Lithologic and radioactivity log of Summit area drill hole, Hardin County, Kentucky: U.S. Geol. Survey open-file report, 1 sheet.

Peterson, W. L., 1966a, Geologic map of the New Haven quadrangle, Nelson and Larue Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-506.

——— 1966b, Geologic map of the Nelsonville quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-564.

——— 1967, Geologic map of the Lebanon Junction quadrangle, central Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-603.

——— 1968, Geologic map of the Cravens quadrangle, Bullitt and Nelson Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-737.

Peterson, W. L., and Kepferle, R. C., 1970, Deltaic deposits of the Borden Formation in central Kentucky, *in* Geological Survey research, 1970: Geol. Survey Prof. Paper 700-D, p. D49-D54. [1971].

Sable, E. G., Kepferle, R. C., and Peterson, W. L., 1966, Harrodsburg Limestone in Kentucky: U.S. Geol. Survey Bull. 1224-I, 12 p.

Stockdale, P. B., 1929, Stratigraphic units of the Harrodsburg limestone: Indiana Acad. Sci. Proc., v. 38, p. 233-242.

——— 1931, The Borden (Knobstone) rocks of southern Indiana: Indiana Dept. Conserv., Div. Geology Pub. 98, 330 p.

——— 1939, Lower Mississippian rocks of the east-central interior: Geol. Soc. America Spec. Paper 22, 248 p.

Taylor, A. R., and Lewis, R. Q., Sr., 1971, Geologic map of the Yosemite quadrangle, Casey and Lincoln Counties, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-910.

Weir, G. W., 1970, Borden Formation (Mississippian) in southeast-central Kentucky, *in* Geol. Soc. America, Southeastern Sec., Guidebook for field trips, 18th Ann. Mtg., Lexington, Ky., 1970: Kentucky Geol. Survey, p. 29-48.

Weir, G. W., Gualtieri, J. L., and Schlanger, S. O., 1966, Borden Formation (Mississippian) in south- and southeast-central Kentucky: U.S. Geol. Survey Bull. 1224-F, 38 p.

U.S. GOVERNMENT PRINTING OFFICE : 1971 O - 443-521

Table 1. Modal analyses of thin sections of siltstones of the Borden Formation

Thin Section Number	Quartz: Common	Quartz: Undulose	Quartz: Polycrystalline	Quartz: (Total)	Feldspar: Orthoclase & Untwinned	Feldspar: Microcline	Feldspar: Plagioclase	Feldspar: (Total)	Chert & Rock Fragments	Mica: Muscovite	Mica: Biotite & Chlorite	Mica: (Total)
	Percentage of minerals in thin sections											
Kenwood Siltstone Member, Kenwood Hill type section, Jefferson County, Ky.												
LW-1-70	34.0	1.5	6.0	(41.5)	27.5	-	Tr	(27.5)	8.0	2.0	-	(2)
LW-1-61	36.3	1.7	7.3	(45.3)	25.0	-	1.0	(26.0)	3.7	2.0	0.3	(2.3)
LW-1-60	30.6	2.3	7.7	(40.6)	26.2	-	0.6	(26.8)	6.1	2.3	1.0	(3.3)
LW-1-60	31.3	2.4	8.0	(41.7)	23.0	.3	0.4	(23.7)	4.3	1.3	-	(1.3)
Bed 6 Average	32.7	2.1	7.7	(42.5)	24.7	0.1	0.7	(25.5)	4.7	1.9	0.4	(2.3)
LW-1-52	29.7	4.0	10.7	(44.4)	22.3	-	1.0	(23.3)	6.0	2.0	0.3	(2.3)
LW-1-50	39.7	1.7	10.3	(51.7)	25.0	-	2.3	(27.3)	7.3	1.0	1.7	(2.7)
Bed 5 Average	34.7	2.8	10.5	(48.0)	23.6	-	1.7	(25.3)	6.7	1.5	1.0	(2.5)
LW-1-43	34.3	2.3	7.7	(44.3)	24.4	-	1.3	(25.7)	7.0	0.7	-	(0.7)
LW-1-42	39.7	3.7	7.6	(51.0)	17.7	0.7	1.6	(20.0)	13.0	1.7	1.0	(2.7)
LW-1-41	19.0	10.7	19.3	(49.0)	13.0	-	1.0	(14.0)	3.3	0.7	1.7	(2.4)
LW-1-40	37.6	0.7	7.6	(45.9)	20.7	-	1.4	(22.1)	3.8	—	—	—
Bed 4 Average	32.65	4.35	10.55	(47.55)	18.95	0.2	1.3	(20.45)	6.8	0.8	0.7	(1.5)
LW-1-36	26.7	3.3	12.3	(42.3)	19.0		2.0	(21.0)	7.3	0.3	0.3	(0.7)
LW-1-35	28.4	4.2	9.0	(41.6)	22.6	0.3	1.6	(25.5)	6.5	1.9	Tr	(1.9)
LW-1-34	29.3	8.0	9.3	(46.7)	12.7	0.3	1.3	(14.3)	6.0	1.7	1.0	(2.7)
LW-1-33	36.4	2.0	8.9	(47.3)	24.8	-	1.0	(25.8)	2.4	2.0	0.7	(2.7)
LW-1-31	40.3	4.0	10.7	(55.0)	14.3	0.3	1.7	(16.3)	5.7	0.7	0.3	(1.0)
LW-1-30	28.0	7.0	11.0	(46.0)	22.3	Tr	1.3	(23.7)	10.0	1.0	0.3	(1.3)
Bed 3 Average	31.5	4.7	10.2	(46.5)	19.3	0.1	1.5	(21.1)	6.3	1.3	0.4	(1.7)
LW-1-23	32.3	3.3	0.3	(36.0)	7.3	-		(7.3)	4.0	1.0	-	(1.0)
LW-1-21	23.0	4.3	8.7	(36.0)	28.0	-	0.7	(28.7)	7.0	2.0	-	(2.0)
LW-1-20	19.0	4.3	14.3	(37.7)	14.3	Tr	Tr	(14.3)	3.0	0.7	-	(0.7)
Bed 2 Average	24.8	4.0	7.8	(36.6)	16.5	Tr	0.2	(16.8)	4.7	1.2	-	(1.2)
LW-1-6	26.7	3.3	18.0	(48.0)	10.3	-	0.3	(10.6)	3.7	1.0	0.7	(1.7)
LW-1-5	40.7	2.3	10.4	(53.4)	16.3	-	1.0	(17.3)	7.3	1.0	0.7	(1.7)
LW-1-4	43.4	1.4	6.6	(51.4)	20.3	-	0.4	(20.7)	5.2	2.5	0.3	(2.8)
LW-1-3	36.3	3.3	13.0	(52.6)	13.3	-	0.7	(14.0)	5.0	0.7	1.0	(1.7)
LW-1-2	45.7	2.3	14.7	(62.7)	13.0	-	1.3	(14.3)	2.0	1.0	0.7	(1.7)
LW-1-1	37.3	7.0	8.0	(52.3)	9.7	-	0.6	(10.3)	3.4	Tr	—	Tr
Bed 1 Average	38.35	3.25	11.8	(53.4)	13.8	-	0.7	(14.5)	4.4	1.0	0.6	(1.6)
Kenwood Hi												
Unweathered Kenwood Siltstone Member, Bullitt County, Ky.												
BR-1-1A	9.3	12.3	5.4	(27.0)	14.3	-	2.7	(17)	1.7	1.3	1.0	(2.3)
BR-1-1B	23.7	13.6	5.0	(42.3)	10.7	-	2.3	(13)	2.0	2.0	0.3	(2.3)
BR-1-1C	15.3	10.3	5.7	(31.3)	9.3	0.7	2.0	(12)	1.7	2.7	1.0	(3.7)
Bed 1 Brooks	16.1	12.1	5.3	(33.5)	11.43	0.23	2.33	(14.0)	1.8	2.0	0.8	(2.8)
Kenwood Siltstone Member, Shepherdsville area, Bullitt County, Ky.												
SH-1-T	37	23		(60)				(1.7)	1.6	1.7		(1.7)
SH-1-M	35	21		(56)				(9.0)	4.0	-		
SH-1-B	43.3	22.7		(66)				(2.7)	1.0	0.3		(0.3)
Bed Average	38.4	22.2		(60.6)				(4.5)	2.2	0.7		(0.7)
SH-2-T	28.8	21.4		(50.2)				(2.9)	3.9	2.5		(2.5)
SH-2-B	40.5	22.6		(63.1)				(3.7)	1.7	2.2		(2.2)
Bed Average	34.65	22.0		(56.65)				(3.3)	2.8	2.35		(2.35)
SH-3T	22.2	20.4		(42.6)				(7.4)	2.8	0.9		(0.9)
SH-3B	26.3	14.5		(40.8)				(2.9)	2.9	2.9		(2.9)
Bed Average	24.25	17.45		(41.7)				(5.15)	2.85	1.9		(1.9)
SH-4	48.0	21		(69.0)				(7.0)	9.0	1.0		(1.0)
SH-5	38.0	18		(56.0)				(5.0)	3.6	0.7		(0.7)
SH-6	28.5	22		(50.5)				(8.5)	4.0	-		—
Bed Average	38.2	20.3		(58.5)				(6.8)	5.5	0.6		(0.6)
SH-16T	47.7	24.3		(72.0)				(3.3)	0.7	0.7	0.7	(1.4)
SH-16B	37.3	26.3		(63.6)				(6.0)	3.7	0.7	0.7	(1.4)
Bed Average	42.5	25.3		(67.8)				(4.65)	2.2	0.7	0.7	(1.4)
Kenwood Siltstone Member, north end Kenwood Hill, Jefferson County, Ky.												
LW-1T	43.0	22.0		(65.0)				(7.0)	6.5	-		
LW-1B	44.0	6.0		(50.0)				(9.0)	4.5	0.5		(0.5)
Bed Average	43.5	14.0		(57.5)				(8.0)	5.5	0.25		(0.25)
Kenwood Siltstone Member, south end Kenwood Hill, Jefferson County, Ky.												
LW-2T	39.3	20.4		(59.7)				(2.0)	1.7	1.0		(1.0)
LW-2B	48.7	10.7		(59.4)				(4.6)	1.0	1.3		(1.3)
Bed Average	44.0	15.55		(59.55)				(3.3)	1.35	1.15		(1.15)
Kenwood Hill Average												
Bullitt County Average												
Total Kenwood Average												
Farmers Siltstone Member, Lewis County, Ky.												
VA-1-2A	9.7	12.0	8.6	(30.3)	20.0	Tr	0.3	(20.3)	7.7	1.3	0.7	(2.0)
VA-1-23	12.7	5.7	8.6	(27.0)	16.3	-	0.7	(17.0)	3.3	0.3	0.7	(1.0)
Bed Average	11.2	8.85	8.6	(28.65)	18.15	Tr -	0.5	(18.65)	5.5	0.8	0.7	(1.5)
"Rockcastle freestone", Wildie Member, Rockcastle County, Ky.												
RF-1-T	14.7	11.6	13.3	(39.6)	17.0	Tr	0.7	(17.7)	0.7	3.6	0.7	(4.3)

Table 1. Modal analyses of thin sections of siltstones of the Borden Formation

Feldspar			Chert & Rock Fragments	Mica			Other Grains	Matrix	Total Grains	Bed average (percent, matrix-free basis)		
icrocline	Plagioclase	(Total)		Muscovite	Biotite & Chlorite	(Total)				Quartz	Feldspar	Chert & Rock Fragments
Kenwood Siltstone Member, Kenwood Hill type section, Jefferson County, Ky.												
-	Tr	(27.5)	8.0	2.0	-	(2)	-	21	77.0	54.0	36.0	10.0
-	1.0	(26.0)	3.7	2.C	0.3	(2.3)	-	22.7				
-	0.6	(26.8)	6.1	2.3	1.0	(3.3)	-	23.2				
.3	0.4	(23.7)	4.3	1.3	-	(1.3)	-	29.0				
0.1	0.7	(25.5)	4.7	1.9	0.4	(2.3)	-	25.0	72.7	58.5	35.0	6.5
-	1.0	(23.3)	6.0	2.0	0.3	(2.3)	-	24.0				
-	2.3	(27.3)	7.3	1.0	1.7	(2.7)	-	11.0				
-	1.7	(25.3)	6.7	1.5	1.0	(2.5)	-	(17.5)	80.0	60.0	32.0	8.0
-	1.3	(25.7)	7.0	0.7	-	(0.7)	-	22.3				
0.7	1.6	(20.0)	13.0	1.7	1.0	(2.7)	-	13.3				
-	1.0	(14.0)	3.3	0.7	1.7	(2.4)	-	31.3				
-	1.4	(22.1)	3.8	—	—	—	—	28.2				
0.2	1.3	(20.45)	6.8	0.8	0.7	(1.5)	-	23.8	74.8	63.5	27.5	9.0
	2.0	(21.0)	7.3	0.3	0.3	(0.7)	-	28.7				
0.3	1.6	(25.5)	6.5	1.9	Tr	(1.9)	-	25.5				
0.3	1.3	(14.3)	6.0	1.7	1.0	(2.7)	-	30.3				
-	1.0	(25.8)	2.4	2.0	0.7	(2.7)	-	21.8				
0.3	1.7	(16.3)	5.7	0.7	0.3	(1.0)	0.3	21.7				
Tr	1.3	(23.7)	10.0	1.0	0.3	(1.3)	-	19.0				
0.1	1.5	(21.1)	6.3	1.3	0.4	(1.7)	Tr	24.5	73.9	63.0	28.5	8.5
-		(7.3)	4.0	1.0	-	(1.0)	-	51.7				
-	0.7	(28.7)	7.0	2.0	-	(2.0)	-	26.3				
Tr	Tr	(14.3)	3.0	0.7	-	(0.7)	-	44.3				
Tr	0.2	(16.8)	4.7	1.2	-	(1.2)	-	40.8	58.1	63.0	29.0	8.0
-	0.3	(10.6)	3.7	1.0	0.7	(1.7)	-	36.0				
-	1.0	(17.3)	7.3	1.0	0.7	(1.7)	1.3	19.0				
-	0.4	(20.7)	5.2	2.5	0.3	(2.8)	0.7	19.2				
-	0.7	(14.0)	5.0	0.7	1.0	(1.7)	0.7	26.0				
-	1.3	(14.3)	2.0	1.0	0.7	(1.7)	0.6	18.7				
-	0.6	(10.3)	3.4	Tr	—	Tr	0.7	33.3				
-	0.7	(14.5)	4.4	1.0	0.6	(1.6)	(0.7)	25.4	72.3	74.0	20.0	6.0
					Kenwood Hill Average				72.4	62	30	8
Unweathered Kenwood Siltstone Member, Bullitt County, Ky.												
-	2.7	(17)	1.7	1.3	1.0	(2.3)	0.3	51.7				
-	2.3	(13)	2.0	2.0	0.3	(2.3)	0.7	39.7				
).7	2.0	(12)	1.7	2.7	1.0	(3.7)	2.3	49.0				
).23	2.33	(14.0)	1.8	2.0	0.8	(2.8)	1.1	46.8	49.3	68	28	4
Kenwood Siltstone Member, Shepherdsville area, Bullitt County, Ky.												
		(1.7)	1.6	1.7		(1.7)		35.0				
		(9.0)	4.0	-			2.0	29.0				
		(2.7)	1.0	0.3		(0.3)	—	30.0				
		(4.5)	2.2	0.7		(0.7)	0.7	31.3	67.3	90.0	6.7	3.3
		(2.9)	3.9	2.5		(2.5)	0.6	39.9				
		(3.7)	1.7	2.2		(2.2)	0.3	29.0				
		(3.3)	2.8	2.35		(2.35)	0.45	34.45	62.8	90.2	5.3	4.5
		(7.4)	2.8	0.9		(0.9)	1.8	44.5				
		(2.9)	2.9	2.9		(2.9)	1.9	48.6				
		(5.15)	2.85	1.9		(1.9)	1.85	46.55	49.7	84.0	10.3	5.7
		(7.0)	9.0	1.0		(1.0)	Tr	14.0				
		(5.0)	3.6	0.7		(0.7)		34.7				
		(8.5)	4.0	-		—		37.0				
		(6.8)	5.5	0.6		(0.6)		28.6	70.8	82.6	9.6	7.8
		(3.3)	0.7	0.7	0.7	(1.4)	0.6	22.0				
		(6.0)	3.7	0.7	0.7	(1.4)	0.6	24.7				
		(4.65)	2.2	0.7	0.7	(1.4)	0.6	23.35	74.65	90.8	6.2	3.0
Kenwood Siltstone Member, north end Kenwood Hill, Jefferson County, Ky.												
		(7.0)	6.5	-				21.5				
		(9.0)	4.5	0.5		(0.5)		36.0				
		(8.0)	5.5	0.25		(0.25)		28.75	71.0	81.0	11.2	7.8
Kenwood Siltstone Member, south end Kenwood Hill, Jefferson County, Ky.												
		(2.0)	1.7	1.0		(1.0)	0.3	35.3				
		(4.6)	1.0	1.3		(1.3)	Tr	33.7				
		(3.3)	1.35	1.15		(1.15)	0.15	34.5	64.2	92.8	5.1	2.1
									71.6	62.0	30.0	8.0
									62.4	84.3	11.0	4.7
									67.9	76.0	18.1	5.9
Farmers Siltstone Member, Lewis County, Ky.												
[illegible]	0.3	(20.3)	7.7	1.3	0.7	(2.0)	0	39.7				
[illegible]	0.7	(17.0)	3.3	0.3	0.7	(1.0)	1.0	30.7				
[illegible]	0.5	(18.65)	5.5	0.8	0.7	(1.5)	0.5	45.15	52.8	54	35.5	10.5
"Rockcastle freestone", Wildie Member, Rockcastle County, Ky.												

							Kenwood Siltstone Member, Kenwood Hill type section, Jefferson County, Ky.					
LW-1-70	34.0	1.5	6.0	(41.5)	27.5	-	Tr	(27.5)	8.0	2.0	-	(2)
LW-1-61	36.3	1.7	7.3	(45.3)	25.0	-	1.0	(26.0)	3.7	2.0	0.3	(2.3)
LW-1-60	30.6	2.3	7.7	(40.6)	26.2	-	0.6	(26.8)	6.1	2.3	1.0	(3.3)
LW-1-60	31.3	2.4	8.0	(41.7)	23.0	.3	0.4	(23.7)	4.3	1.3	-	(1.3)
Bed 6												
Average	32.7	2.1	7.7	(42.5)	24.7	0.1	0.7	(25.5)	4.7	1.9	0.4	(2.3)
LW-1-52	29.7	4.0	10.7	(44.4)	22.3	-	1.0	(23.3)	6.0	2.0	0.3	(2.3)
LW-1-50	39.7	1.7	10.3	(51.7)	25.0	-	2.3	(27.3)	7.3	1.0	1.7	(2.7)
Bed 5												
Average	34.7	2.8	10.5	(48.0)	23.6	-	1.7	(25.3)	6.7	1.5	1.0	(2.5)
LW-1-43	34.3	2.3	7.7	(44.3)	24.4	-	1.3	(25.7)	7.0	0.7	-	(0.7)
LW-1-42	39.7	3.7	7.6	(51.0)	17.7	0.7	1.6	(20.0)	13.0	1.7	1.0	(2.7)
LW-1-41	19.0	10.7	19.3	(49.0)	13.0	-	1.0	(14.0)	3.3	0.7	1.7	(2.4)
LW-1-40	37.6	0.7	7.6	(45.9)	20.7	-	1.4	(22.1)	3.8			
Bed 4												
Average	32.65	4.35	10.55	(47.55)	18.95	0.2	1.3	(20.45)	6.8	0.8	0.7	(1.5)
LW-1-36	26.7	3.3	12.3	(42.3)	19.0		2.0	(21.0)	7.3	0.3	0.3	(0.7)
LW-1-35	28.4	4.2	9.0	(41.6)	22.6	0.3	1.6	(25.5)	6.5	1.9	Tr	(1.9)
LW-1-34	29.3	8.0	9.3	(46.7)	12.7	0.3	1.3	(14.3)	6.0	1.7	1.0	(2.7)
LW-1-33	36.4	2.0	8.9	(47.3)	24.8	-	1.0	(25.8)	2.4	2.0	0.7	(2.7)
LW-1-31	40.3	4.0	10.7	(55.0)	14.3	0.3	1.7	(16.3)	5.7	0.7	0.3	(1.0)
LW-1-30	28.0	7.0	11.0	(46.0)	22.3	Tr	1.3	(23.7)	10.0	1.0	0.3	(1.3)
Bed 3												
Average	31.5	4.7	10.2	(46.5)	19.3	0.1	1.5	(21.1)	6.3	1.3	0.4	(1.7)
LW-1-23	32.3	3.3	0.3	(36.0)	7.3	-		(7.3)	4.0	1.0	-	(1.0)
LW-1-21	23.0	4.3	8.7	(36.0)	28.0	-	0.7	(28.7)	7.0	2.0	-	(2.0)
LW-1-20	19.0	4.3	14.3	(37.7)	14.3	Tr	Tr	(14.3)	3.0	0.7	-	(0.7)
Bed 2												
Average	24.8	4.0	7.8	(36.6)	16.5	Tr	0.2	(16.8)	4.7	1.2	-	(1.2)
LW-1-6	26.7	3.3	18.0	(48.0)	10.3	-	0.3	(10.6)	3.7	1.0	0.7	(1.7)
LW-1-5	40.7	2.3	10.4	(53.4)	16.3	-	1.0	(17.3)	7.3	1.0	0.7	(1.7)
LW-1-4	43.4	1.4	6.6	(51.4)	20.3	-	0.4	(20.7)	5.2	2.5	0.3	(2.8)
LW-1-3	36.3	3.3	13.0	(52.6)	13.3	-	0.7	(14.0)	5.0	0.7	1.0	(1.7)
LW-1-2	45.7	2.3	14.7	(62.7)	13.0	-	1.3	(14.3)	2.0	1.0	0.7	(1.7)
LW-1-1	37.3	7.0	8.0	(52.3)	9.7	-	0.6	(10.3)	3.4	Tr		Tr
Bed 1												
Average	38.35	3.25	11.8	(53.4)	13.8	-	0.7	(14.5)	4.4	1.0	0.6	(1.6)
												Kenwood Hil
							Unweathered Kenwood Siltstone Member, Bullitt County, Ky.					
BR-1-1A	9.3	12.3	5.4	(27.0)	14.3	-	2.7	(17)	1.7	1.3	1.0	(2.3)
BR-1-1B	23.7	13.6	5.0	(42.3)	10.7	-	2.3	(13)	2.0	2.0	0.3	(2.3)
BR-1-1C	15.3	10.3	5.7	(31.3)	9.3	0.7	2.0	(12)	1.7	2.7	1.0	(3.7)
Bed 1												
Brooks	16.1	12.1	5.3	(33.5)	11.43	0.23	2.33	(14.0)	1.8	2.0	0.8	(2.8)
							Kenwood Siltstone Member, Shepherdsville area, Bullitt County, Ky.					
SH-1-T	37	23		(60)				(1.7)	1.6	1.7		(1.7)
SH-1-M	35	21		(56)				(9.0)	4.0	-		
SH-1-B	43.3	22.7		(66)				(2.7)	1.0	0.3		(0.3)
Bed												
Average	38.4	22.2		(60.6)				(4.5)	2.2	0.7		(0.7)
SH-2-T	28.8	21.4		(50.2)				(2.9)	3.9	2.5		(2.5)
SH-2-B	40.5	22.6		(63.1)				(3.7)	1.7	2.2		(2.2)
Bed												
Average	34.65	22.0		(56.65)				(3.3)	2.8	2.35		(2.35)
SH-3T	22.2	20.4		(42.6)				(7.4)	2.8	0.9		(0.9)
SH-3B	26.3	14.5		(40.8)				(2.9)	2.9	2.9		(2.9)
Bed												
Average	24.25	17.45		(41.7)				(5.15)	2.85	1.9		(1.9)
SH-4	48.0	21		(69.0)				(7.0)	9.0	1.0		(1.0)
SH-5	38.0	18		(56.0)				(5.0)	3.6	0.7		(0.7)
SH-6	28.5	22		(50.5)				(8.5)	4.0			
Bed												
Average	38.2	20.3		(58.5)				(6.8)	5.5	0.6		(0.6)
SH-16T	47.7	24.3		(72.0)				(3.3)	0.7	0.7	0.7	(1.4)
SH-16B	37.3	26.3		(63.6)				(6.0)	3.7	0.7	0.7	(1.4)
Bed												
Average	42.5	25.3		(67.8)				(4.65)	2.2	0.7	0.7	(1.4)
							Kenwood Siltstone Member, north end Kenwood Hill, Jefferson County, Ky.					
LW-1T	43.0	22.0		(65.0)				(7.0)	6.5	-		
LW-1B	44.0	6.0		(50.0)				(9.0)	4.5	0.5		(0.5)
Bed												
Average	43.5	14.0		(57.5)				(8.0)	5.5	0.25		(0.25)
							Kenwood Siltstone Member, south end Kenwood Hill, Jefferson County, Ky.					
LW-2T	39.3	20.4		(59.7)				(2.0)	1.7	1.0		(1.0)
LW-2B	48.7	10.7		(59.4)				(4.6)	1.0	1.3		(1.3)
Bed												
Average	44.0	15.55		(59.55)				(3.3)	1.35	1.15		(1.15)
Kenwood Hill Average												
Bullitt County Average												
Total Kenwood Average												
							Farmers Siltstone Member, Lewis County, Ky.					
VA-1-2A	9.7	12.0	8.6	(30.3)	20.0	Tr	0.3	(20.3)	7.7	1.3	0.7	(2.0)
VA-1-23	12.7	5.7	8.6	(27.0)	16.3	- Tr	0.7	(17.0)	3.3	0.3	0.7	(1.0)
Bed												
Average	11.2	8.85	8.6	(28.65)	18.15	-	0.5	(18.65)	5.5	0.8	0.7	(1.5)
							"Rockcastle freestone", Wildie Member, Rockcastle County, Ky.					
RF-1-T	14.7	11.6	13.3	(39.6)	17.0	Tr	0.7	(17.7)	0.7	3.6	0.7	(4.3)
RF-1-M	11.3	13.0	13.3	(37.7)	23.3	-	1.3	(24.7)	0.3	1.7	6.0	(7.7)
RF-1-B	10.0	14.7	8.3	(33.0)	16.3	0.3	1.4	(18.0)	1.3	3.7	0.6	(4.3)
Bed												
Average	12.0	13.1	11.6	(26.8)	18.9	0.1	1.1	(20.1)	1.8	3.0	2.4	(5.4)
							Holtsclaw Siltstone Member, Bullitt County, Ky.					
Holtsclaw	27	13		(40.0)				(5.0)	3.0			

Kenwood Siltstone Member, Kenwood Hill type section, Jefferson County, Ky.												
-	Tr	(27.5)	8.0	2.0	-	(2)	-	21	77.0	54.0	36.0	10.0
-	1.0	(26.0)	3.7	2.0	0.3	(2.3)	-	22.7				
-	0.6	(26.8)	6.1	2.3	1.0	(3.3)	-	23.2				
.3	0.4	(23.7)	4.3	1.3	-	(1.3)	-	29.0				
0.1	0.7	(25.5)	4.7	1.9	0.4	(2.3)	-	25.0	72.7	58.5	35.0	6.5
-	1.0	(23.3)	6.0	2.0	0.3	(2.3)	-	24.0				
-	2.3	(27.3)	7.3	1.0	1.7	(2.7)	-	11.0				
-	1.7	(25.3)	6.7	1.5	1.0	(2.5)	-	(17.5)	80.0	60.0	32.0	8.0
-	1.3	(25.7)	7.0	0.7	-	(0.7)	-	22.3				
0.7	1.6	(20.0)	13.0	1.7	1.0	(2.7)	-	13.3				
-	1.0	(14.0)	3.3	0.7	1.7	(2.4)	-	31.3				
-	1.4	(22.1)	3.8					28.2				
0.2	1.3	(20.45)	6.8	0.8	0.7	(1.5)	-	23.8	74.8	63.5	27.5	9.0
	2.0	(21.0)	7.3	0.3	0.3	(0.7)	-	28.7				
0.3	1.6	(25.5)	6.5	1.9	Tr	(1.9)	-	25.5				
0.3	1.3	(14.3)	6.0	1.7	1.0	(2.7)	-	30.3				
-	1.0	(25.8)	2.4	2.0	0.7	(2.7)	-	21.8				
0.3	1.7	(16.3)	5.7	0.7	0.3	(1.0)	0.3	21.7				
Tr	1.3	(23.7)	10.0	1.0	0.3	(1.3)	-	19.0				
0.1	1.5	(21.1)	6.3	1.3	0.4	(1.7)	Tr	24.5	73.9	63.0	28.5	8.5
-		(7.3)	4.0	1.0	-	(1.0)	-	51.7				
-	0.7	(28.7)	7.0	2.0	-	(2.0)	-	26.3				
Tr	Tr	(14.3)	3.0	0.7	-	(0.7)	-	44.3				
Tr	0.2	(16.8)	4.7	1.2	-	(1.2)	-	40.8	58.1	63.0	29.0	8.0
-	0.3	(10.6)	3.7	1.0	0.7	(1.7)	-	36.0				
-	1.0	(17.3)	7.3	1.0	0.7	(1.7)	1.3	19.0				
-	0.4	(20.7)	5.2	2.5	0.3	(2.8)	0.7	19.2				
-	0.7	(14.0)	5.0	0.7	1.0	(1.7)	0.7	26.0				
-	1.3	(14.3)	2.0	1.0	0.7	(1.7)	0.6	18.7				
-	0.6	(10.3)	3.4	Tr		Tr	0.7	33.3				
-	0.7	(14.5)	4.4	1.0	0.6	(1.6)	(0.7)	25.4	72.3	74.0	20.0	6.0
						Kenwood Hill Average			72.4	62	30	8
Unweathered Kenwood Siltstone Member, Bullitt County, Ky.												
-	2.7	(17)	1.7	1.3	1.0	(2.3)	0.3	51.7				
-	2.3	(13)	2.0	2.0	0.3	(2.3)	0.7	39.7				
0.7	2.0	(12)	1.7	2.7	1.0	(3.7)	2.3	49.0				
0.23	2.33	(14.0)	1.8	2.0	0.8	(2.8)	1.1	46.8	49.3	68	28	4
Kenwood Siltstone Member, Shepherdsville area, Bullitt County, Ky.												
		(1.7)	1.6	1.7		(1.7)		35.0				
		(9.0)	4.0	-			2.0	29.0				
		(2.7)	1.0	0.3		(0.3)		30.0				
		(4.5)	2.2	0.7		(0.7)	0.7	31.3	67.3	90.0	6.7	3.3
		(2.9)	3.9	2.5		(2.5)	0.6	39.9				
		(3.7)	1.7	2.2		(2.2)	0.3	29.0				
		(3.3)	2.8	2.35		(2.35)	0.45	34.45	62.8	90.2	5.3	4.5
		(7.4)	2.8	0.9		(0.9)	1.8	44.5				
		(2.9)	2.9	2.9		(2.9)	1.9	48.6				
		(5.15)	2.85	1.9		(1.9)	1.85	46.55	49.7	84.0	10.3	5.7
		(7.0)	9.0	1.0		(1.0)	Tr	14.0				
		(5.0)	3.6	0.7		(0.7)		34.7				
		(8.5)	4.0	-				37.0				
		(6.8)	5.5	0.6		(0.6)		28.6	70.8	82.6	9.6	7.8
		(3.3)	0.7	0.7	0.7	(1.4)	0.6	22.0				
		(6.0)	3.7	0.7	0.7	(1.4)	0.6	24.7				
		(4.65)	2.2	0.7	0.7	(1.4)	0.6	23.35	74.65	90.8	6.2	3.0
Kenwood Siltstone Member, north end Kenwood Hill, Jefferson County, Ky.												
		(7.0)	6.5	-				21.5				
		(9.0)	4.5	0.5		(0.5)		36.0				
		(8.0)	5.5	0.25		(0.25)		28.75	71.0	81.0	11.2	7.8
Kenwood Siltstone Member, south end Kenwood Hill, Jefferson County, Ky.												
		(2.0)	1.7	1.0		(1.0)	0.3	35.3				
		(4.6)	1.0	1.3		(1.3)	Tr	33.7				
		(3.3)	1.35	1.15		(1.15)	0.15	34.5	64.2	92.8	5.1	2.1
									71.6	62.0	30.0	8.0
									62.4	84.3	11.0	4.7
									67.9	76.0	18.1	5.9
Farmers Siltstone Member, Lewis County, Ky.												
Tr	0.3	(20.3)	7.7	1.3	0.7	(2.0)	0	39.7				
Tr	0.7	(17.0)	3.3	0.3	0.7	(1.0)	1.0	50.7				
-	0.5	(18.65)	5.5	0.8	0.7	(1.5)	0.5	45.15	52.8	54	35.5	10.5
"Rockcastle freestone", Wildie Member, Rockcastle County, Ky.												
Tr	0.7	(17.7)	0.7	3.6	0.7	(4.3)		37.7				
-	1.3	(24.7)	0.3	1.7	6.0	(7.7)	1.3	25.3				
.3	1.4	(18.0)	1.3	3.7	0.6	(4.3)	Tr	43.3				
.1	1.1	(20.1)	1.8	3.0	2.4	(5.4)	0.4	35.4	48.7	55	41	4
Holtsclaw Siltstone Member, Bullitt County, Ky.												
		(5.0)	3.0					52.0	48	83.3	10.4	6.3